Evaluation of Microclimates and Thermal Perceptions in Urban Precincts

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Statement of Authorship

I, *Salman Shooshtarian*, declare that:

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Abstract

The fast pace of urbanisation has led to more built up spaces in many urbanised areas. Urbanised areas influence surrounding microclimates, which in turn, affect users' thermal perceptions, well- being and outdoor usage patterns. Thermal comfort, which has been extensively studied and used for indoor spaces such as offices and residential buildings, is one of the measures used to assess outdoor spaces. In the absence of outdoor thermal comfort standards, the researchers studying thermal comfort in outdoor urban areas have begun to take advantage of the standards developed for indoor conditions (ISO 7730 2006, ASHRAE 55 2010) to assess outdoor thermal perceptions. However, there are some debates about the adequacy of such standards in various contexts including indoor and outdoor conditions. Some thermal comfort literature has emphasized on the necessity for revising the 'philosophy' that forms the comfort standards, which was the stance of the adaptive approach to thermal comfort. In contrast to heat balance theories, the adaptive thermal comfort model includes some influential contextual factors in the assessment of thermal comfort. Australia and particularly Melbourne, capital city of Victoria, is one of the world's major education providers. Each year many students are admitted to Australian universities and the number of local and international students is expected to rise in the future. The resultant urbanisation in Australia's cities has created modified meteorological conditions affecting people's thermal comfort. A university campus attended by people from different climatic backgrounds represents an environment with varying thermal expectations and preferences, providing a great opportunity to investigate the extent of influence of contextual factors on people's thermal perceptions and applicability of the existing standards. Consequently, this study was carried out at the RMIT University City Campus, an educational urban precinct located in the heart of Melbourne's central business district (CBD).

This study developed a research hypothesis, "existing thermal comfort standards are not adequate to assess the determinants of outdoor thermal comfort conditions", to investigate the applicability of the assumptions enshrined in the thermal comfort standards in the context of educational urban precincts in Melbourne. Accordingly, three research questions were formulated to navigate the research: (1) to what extent are the thermal comfort standards applicable to educational urban precincts in Australian cities? (2) to what extent can contextual factors influence outdoor users' thermal perceptions? and (3) what are the factors influencing usage patterns and behaviours in educational outdoor spaces? To investigate people's interaction with

thermal conditions in outdoor built environments, three rounds of field surveys (spring 2014, summer 2015, and autumn 2015) were conducted. Field surveys consisted of questionnaire surveys and concurrent measurements of four environmental parameters that are best known to have the most impact on people's thermal subjective assessment: air temperature (T_a), relative humidity (RH), wind speed (V_a) and radiant temperature (T_g). The questionnaire was structured according to ISO 7730, ASHRAE 55, and ISO 10551 and aimed to capture people's thermal perceptions (including thermal sensation, preference, acceptability, and overall comfort). Three thermal comfort indices, namely Physiological Equivalent Temperature (PET), Outdoor Thermal Climate Index (UTCI) and Outdoor Standard Effective Temperature (OUT-SET*) were employed to predict thermal comfort conditions using the four thermal factors and two personal parameters (level of activity and clothing insulation).

In total, 1059 questionnaires were collected from the three sites of RUCC. The findings on usage pattern of study sites showed that "time of the day" and "weather conditions" were the two major determinants of people's outdoor attendance. The results revealed that the main assumptions regarding the orthodoxy of thermal comfort (thermal neutrality/neutral temperature[1] and acceptable thermal range[2]) being based on thermal sensation scale was not applicable to the context of an education precinct in Melbourne. Instead, the derivative of thermal preference scale (preferred temperature[3]) was found to be a better representative of people's thermal satisfaction and thus thermal acceptance. Therefore, a multi-model research framework was developed to understand the discrepancy between the patterns of observed comfort data and recommendations enshrined in standards regarding thermal satisfaction. This framework consisted of "Socio-ecological system model (SESM)", "theory of Alliesthesia" and "theory of rising expectations". The modified version of SESM in this study assumes that several contextual factors clustered under five environments (individual, social, physical, psychological, and standards and guidelines) influence people's thermal sensations. The results obtained from the analyses of SESM environments suggested that in total, 12 out of 29 context-specific factors were identified as having a medium impact on people's thermal sensations. The findings are in line with the notion of adaptive comfort theory according to which non-thermal factors can influence people's thermal expectations, preferences, and thus their thermal satisfaction.

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[1] **Neutral temperature:** is a temperature at which most people feel neither cool nor warm here are two methods to define the neutral temperature: a. to define it by solving zero to the equation of linear regression between MTSV and index temperature values, b. to define it using Probit analysis for two categories of "warmer than neutral" and "cooler than neutral"

[2] **Acceptable thermal range:** acceptable thermal conditions should be acceptable to a large number of people (80%-according to ASHRAE, 55, 2010) in typical conditions**.** The most common method to define acceptable thermal range is to use "three central categories" of TSV as acceptable thermal conditions and then finding the two points of intersection between the line of 20% of thermal unacceptability (for outdoor conditions) and the curve of thermal unacceptability over various index temperature values.

[3] **Preferred temperature:** is a temperature at which people require no change in the current weather conditions. To define preferred temperature the three-point scale of McIntyre (1980) on preference is split into the two categories of "change to lower temperature" and "change to higher temperature" and a temperature at which the Probit curves of "change to lower temperature" and "change to higher temperature" cross is the preferred temperature.

The psychological concept of "Alliesthesia" was used to explain the noticeable variations found in the people's preferred temperature in different seasons. This concept refers to the notion of "thermal pleasure" whereby people prefer an opposite thermal status once they have had enough experience of current thermal conditions, since repeated exposure diminishes its desirability over time. In other words, people perceive a warm or cold stimulus to be pleasant or unpleasant when their body core temperature is above or under normal conditions. In winter, people yearn for the warmer conditions of the summer months, while in the heat of summer, they yearn for cooler winter conditions. The last component of this framework, "rising expectations", justified higher thermal expectations of people interviewed in this study (local and international students studying in an Australian university) by referring to their tendency to set greater life standards including higher thermal expectations. According to this theory, when there are some improvements in people's quality of life, they tend to get used to it and even raise it; dissatisfaction occurs when there is a failure in constant provision of such ideal conditions. Highlighting the inadequacy of current thermal comfort standards, this study attempted to indicate the need for revisiting such standards whereby the results of comfort assessments will be better representative of thermal comfort requirements in real world conditions. The accurate definition of thermal comfort requirements will provide a platform to improve outdoor thermal conditions and advance other related disciplines, including but not limited to, urban design, planning, urban meteorology, and health and safety.

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LIST OF PUBLICATIONS

- A review of thermal adaptive strategies in outdoor spaces. *Renewable and Sustainable Energy Reviews*. Under review. Submitted on 04.06.2017.

- Effect of seasonal changes on usage pattern and behaviours in educational precinct in Melbourne. *Urban Climate.* Under review. Submitted on 12.05.2017

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- The effect of physical and psychological environments on the users' thermal perceptions of educational urban precincts. 2017. *Building and Environment*. 115(2017): 182-198.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

LIST OF ACRONYMS

Acronym	*Word form*
ABS	*Australian Bureau of Statistics*
ASHRAE	*American Society of Heating, Refrigerating, and Air Conditioning Engineers*
BOM	*Bureau of Meteorology*
CBD	*Central Business District*
Clo	*Clothing Insulation*
EST	*Ecological System Theory*
H/W	*Aspect Ratio*
ISB	*International Society of Biometeorology*
ISO	*International Standard Organisation*
MEMI	*Munich Energy-balance Model for Individuals*
met	*metabolic activity*
MTSV	*Mean Thermal Sensation Vote*
OLRM	*Ordinal Logistic Regression Model*
OUT-SET	*Outdoor Standard Effective Temperature*
PET	*Physiological Equivalent Temperature*
PMV	*Predicted Mean Vote*
PPD	*Percentage of People Dissatisfied*
RH	*Relative Humidity*

RUCC	*RMIT University City Campus*
SES	*Socio-Technical System*
SESM	*Socio-Ecological System Model*
SET*	*Standard Effective Temperature*
SVF	*Sky View Factor*
T_a	*Air Temperature*
T_g	*Globe (Radiant)Temperature*
T_{mrt}	*Mean Radiant Temperature*
T_n	*Neutral temperature*
T_{pref}	*Preferred temperature*
T_s	*Surface Temperature*
TSV	*Thermal Sensation Vote*
UHI	*Urban Heat Island*
UTCI	*Universal Thermal Climate Index*
V_a	*Air (Wind) Velocity*
WMO	*World Meteorological Organization*

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

The fast pace of urban development across developed countries such as Australia has caused vegetation loss and increased the number of built-up areas. This transition from natural spaces to hard or built up surfaces in cities has led to a sequence of adverse events including damage to ecological systems, and elevated air and surface temperature called urban heat island effects (Oke 1982, Akbari and Taha 1992). The resultant higher temperature values along with recent changes in ecosystems adversely influence the liveability of outdoor built environments, which in turn affects people's thermal perceptions and usage patterns (Wilmers 1991, Unger 1999, Sima 2013). The collective effects of these changes in urban outdoor spaces challenge the effective urban planning to create successful and comfortable outdoor spaces that can facilitate urban residents' interaction with their surrounding environment while meeting their everyday demands. Hence, urban planners have attempted to reason the common grounds according to which people perceive outdoor environments and are able to interact with them, given that people tend to adapt to or improve their environments to achieve comfort.

Regarding the determinants of the quality of outdoor environments, high priority is given to ambient climatic conditions (Nikolopoulou et al. 2001). The use of outdoor spaces is highly dependent on climatic conditions and thermally uncomfortable outdoor spaces may discourage participation in outdoor activities and raise indoor cooling energy consumption. The effective and valid assessment of the level of human comfort in outdoor thermal environments can provide planners and designers with valuable information. This information is leading to more informed decisions on the design and development of urban spaces to ensure the quality of urban life (Frank et al. 2003, Emmanuel 2005) and reduction in cooling loads in buildings (Doulos et al. 2004). Researchers studying thermal comfort in outdoor urban areas have begun to take advantage of the standards developed for indoor conditions (ISO 7730 2006, ASHRAE 55 2010) to assess people's thermal perceptions in urban spaces that are subject to ecological issues.

The term "thermal comfort" as a thermal conditions indicator came into being about fifty years ago, as building designers realized that the introduction of heating systems and mechanical cooling systems (in the 18th and the early 20th centuries, respectively) to the construction market created issues concerning overheating or overcooling in buildings. The widely accepted thermal comfort definition developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers is "*…that condition of mind that expresses satisfaction with the thermal* environment" by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE 55 2010, p. 7). Two models have underpinned the thermal comfort criteria that dominate comfort research and enhanced the science of thermal comfort: firstly, the steady state heat-balance theory model (Fanger 1970); and secondly, the adaptive models (de Dear et al. 1997).

1.2 THE SCIENCE OF COMFORT

The heat-exchange theories mentioned above are technically premised on the notion that parameters impacting directly on the heat balance determine human thermal comfort (Fanger 1970). In these theories (Gagge et al. 1941, Fanger 1970); it is assumed that thermal perceptions are the function of the intensity of physiological responses, as evaluated by the mean skin temperature and latent heat loss (Benzinger 1979) under steady-state conditions. The validity of the heat-balance model was tested using laboratory-experiments in climate chambers and under steady-state conditions (McIntyre 1982). However, the evidence generated in several field experiments showed that the traditional theory of thermal comfort, which only considers thermal factors and not human parameters, might not be applicable in all contexts, i.e. geographical zones and socio-cultural settings (Nicol 1974, Kempton and Lutzenhiser 1992, de Dear and Brager 1998, Nikolopoulou et al. 2001).

Hence, since the mid-1970s, advances in thermal comfort studies have expanded to include contextual factors such as psychosocial and cultural parameters, indirectly interacting with thermal expectations and preferences (Nicol 1974, Auliciems 1981, de Freitas 1985, Kempton and Lutzenhiser 1992, Humphreys 1994, de Dear et al. 1997). These efforts focused on developing comfort theories that consider factors other than thermal in the matrix of thermal comfort, and hence the school of thought in thermal comfort, the adaptive paradigm, came about to add more human parameters to the process of thermal comfort modelling. The field studies of thermal comfort conducted in actual buildings were used as chief instruments in the adaptive modelling approach (Nicol and Humphreys 2002). The adaptive paradigm is assumed to provide the opportunity to specify thermal satisfaction according to the context of study instead of generalising overall conclusions for various contextual conditions. This model was then introduced in the thermal comfort standards; however, its application is only limited to naturally ventilated buildings and is indicative of a relationship between comfort temperature and outdoor temperature. On this basis, some thermal comfort researchers argued that the limited application of adaptive paradigm and comfort standards in general is not adequate to thoroughly represent thermal satisfaction in a thermal environment (Williamson et al. 1989, Shove 2003).

1.3 RATIONALE FOR RESEARCH

Some studies on comfort conditions have stressed the necessity for revising the 'philosophy' that forms the comfort standards, which is different from the stance of the adaptive approach to thermal comfort (Williamson et al. 1989, Humphreys and Nicol 1998, Brager and de Dear 1998, Shove 2003). This necessity has emerged from the assumption that the current thermal comfort assessment methods built upon heat-balance theory might not adequately reflect the level of people's thermal satisfaction. The challenge in the process of revision is the redefinition of "contemporary meaning and expectations of comfort" (Shove 2003). This necessity arose from recent research findings questioning the foundations of comfort standards in the determination of thermal neutrality and satisfaction; these findings suggest that the assessing techniques entrenched in comfort standards are not fully applicable in every context.

Indeed, the criticism received by the comfort assessing techniques is mainly rooted in three issues. These include: the failure to consider the role of contextual conditions in people's thermal perceptions, uncertainties about interpretation of human thermal responses voted on different perceptual indicators, and the inability to differentiate individuals under steady-state and non-steady state conditions when determining thermal satisfaction particularly in outdoor spaces (Höppe 2002). The contextual conditions are represented by the characteristics of individual, psychological, social, and physical factors that modify people's thermal expectations and perceptions (Kempton and Lutzenhiser 1992, Brager and de Dear 1998, Shove 2003). The varied conceptual differences between perceptual indicators of thermal conditions could potentially lead to confusion over the precise interpretation of actual thermal satisfaction. As people who attend outdoor spaces are often under non-steady state conditions, the use of assessing techniques recommended by standards that are based on steady-state conditions is problematic. The idea of revision to standards would re-structure the argument around the human place relationships with respect to their thermal preference and expectations. It also provides a new way of understanding choice, change and connection with an outdoor space that consequently would lead to developing guidelines specifically concerned with the comfort of outdoor thermal environments (Nikolopoulou et al. 2001).

In the context of Australia, while the comfort conditions of indoor spaces have been widely investigated, few studies have explored thermal comfort conditions in open spaces (de Freitas 1985, Spagnolo and de Dear 2003, d'Argent 2012, Loughnan et al. 2012, Kenawy 2013, Lam et al. 2016). The ensuing results have partially acknowledged the role of contextual factors in shaping people's thermal perceptions in Australian open spaces, which are attended by people from diverse climatic backgrounds. These multicultural spaces have accommodated people with various expectations of and preference for thermal conditions. Of these studies only a very few specified the level of thermal satisfaction (de Freitas 1985, Spagnolo and de Dear 2003, d'Argent 2012, Lam et al. 2016) and delved into the characteristics of study populations to explain human place relationships under the local climate conditions (de Freitas 1985, Spagnolo and de Dear 2003). Furthermore, none of these studies has focused on characterising the specific human place relationships in outdoor built environments of education precincts. Therefore, this research set out to explore the adequacy of standards-recommended assessing techniques in determining outdoor thermal satisfaction in the context of an Australian educational urban precinct.

1.4 AN OUTDOOR THERMAL COMFORT STUDY IN MELBOURNE

This study selected three open spaces of an education precinct as the case study studies to investigate how the contextual conditions contributed to outdoor users' thermal satisfaction. These study sites are the premises of RMIT University City Campus (RUCC) in Melbourne's Central Business District (CBD). The distinctive nature of a university campus accommodating people from diverse cultural and geographical backgrounds was used as a learning platform to investigate the extent of contextual factors that impact on people's thermal perceptions. The selected case studies also set the basis for learning about the role of a place's character in thermal satisfaction and usage pattern in outdoor spaces. Chapter 6 describes in full the case studies as well as the site selection criteria.

1.5 RESEARCH HYPOTHESIS, AIM AND OBJECTIVES

Users of both indoor and outdoor spaces need comfortable thermal conditions to maximise effectiveness. This research studied the determinants of human place relationships using assessment techniques entrenched in thermal comfort standards. In the absence of standards devised specifically for outdoor thermal comfort conditions, the assessment procedures in outdoor spaces take advantage of the indoor thermal comfort that may not be adequate to explain people's interactions with open spaces as active agents. The main research hypothesis this study, therefore, was "*existing thermal comfort standards are not adequate to assess the determinants of outdoor thermal comfort conditions*". Understanding people's responses to microclimates involves evaluation of the thermal environment through both physical measurements and users' perceptions. This study outlined the following objectives to provide insights into the depth of research on assessment of thermal comfort requirements in open spaces of education precincts. For each research objective, a few outcomes had to be achieved as follows:

1. *To study the applicability of thermal comfort standards in the Australian context, specifically Melbourne, Victoria;*
    - Creation of seasonal and aggregated database on thermal responses corresponding to thermal environments and of outdoor users
    - Documentation of comfort conditions in the outdoor spaces within a highly-urbanised area;

- Understanding the comfort requirements of the users in different seasons in education precincts and compare these with previous findings;
- Contribution to the investigation of thermal perceptions and expectations in an Oceanic climate with highly variable weather conditions in different seasons,

2. *To examine the influence of contextual factors on users' thermal perceptions*

- Analysing the acquired data to understand the relationships between the contextual factors such as individual, social, physical, and psychological and thermal perceptions;
- Developing a model to study the contextual conditions in relation to thermal expectations and comfort requirements.

3. *To evaluate the influence of outdoor climate conditions on people's usage and behaviour in outdoor environments;*

- Delineation of the pattern of usage in outdoor spaces that represent the typical public spaces in a highly built-up area;
- Understanding the differences between open spaces in terms of usage patterns

1.6 RESEARCH QUESTIONS

The use of outdoor spaces hinges on human interaction with a range of factors. Among these, climate conditions, perceptions and human parameters including socio-psychological factors are known as the most influential factors (Brager and de Dear 1998). The latter may indirectly influence thermal expectations and preferences and thus satisfaction with thermal environments. This research also evaluated the usage pattern of outdoor space users with an emphasis on thermal comfort. The following research questions guide the research direction and address the objectives set out above:

1. To what extent are the thermal comfort standards applicable to education urban precincts in the context of Australian cities?
2. To what extent can contextual factors influence outdoor users' thermal perceptions?

3. What are the factors influencing usage pattern and behaviour in educational outdoor spaces?

1.7 METHODOLOGY

Instrumental to this research is the field survey, classified as a Class-II field experiment consisting of monitoring and measurements of outdoor meteorological conditions and subjective assessments. Field surveys were conducted in three outdoor spaces in an education precinct utilising laboratory-grade instrumentation complying with the specifications and procedures enshrined in the standards (ASHRAE 55 2010, ISO 7730 2006) and the subjective assessment of meteorological conditions were performed by means of questionnaire surveys and supplementary observations. Unobtrusive observations were the third method of data collection to identify people's usage pattern in outdoor spaces under various outdoor microclimate conditions. However, as the specifications of thermal comfort and usage pattern in outdoor spaces hinges on the varied factors, the following structure was in place to develop a framework for the research:

- Examination of the applicability of current thermal comfort assessing methods that are enshrined in thermal comfort by comparing subjective assessment of thermal comfort with thermal comfort predictions;
- Identification of contextual factors that may influence people's thermal judgement;
- Categorisation of the identified contextual factors under different clusters (environments) and investigating their impact on people's thermal perception by using statistical analysis;
- Explaining how people perceive outdoor thermal conditions and use outdoor spaces by analysing field survey and observation data.

The core of this research is the thermal responses of the survey population visiting the study sites, and confronting the given outdoor meteorological conditions daily. The focus on the context conditions involves non-thermal factors connected to the thermal judgements of the survey participants in this research. Therefore, the research aimed to understand how interconnected contextual factors may contribute to forming thermal perceptions.

1.8 THESIS OUTLINE

The thesis consists of ten chapters that are summarised here. Each chapter has an introduction providing an overview of the main contents, and a summary at the end that briefly concludes the main themes covered. Chapters 2 to 3 together present the literature review part of the thesis. **Chapter 2** introduces the concept of thermal comfort by characterising the assessment procedure of thermal satisfaction established in thermal comfort standards. Then it reviews the existing knowledge of the adaptive thermal comfort to highlight the position of thermal adaptation in the science of thermal comfort. Following establishing the principles of thermal comfort in this chapter, **Chapter 3** reviews these principles in the comfort literature concerning the assessment of outdoor thermal comfort. Chapter 3 sheds light on specifications of comfort studies worldwide and particularly in Australia. The chapter also critically reviews previous studies on outdoor thermal comfort to identify the influential contextual factors (thermal and non-thermal) on people’s thermal perceptions and usage pattern in outdoor spaces.

Chapter 4 explains the methodology used in this study to address the research questions and therefore it explains the steps taken to achieve the research aim and objectives. This chapter presents a multi-model research framework to investigate and interpret the field survey data. For the empirical nature of the research, this study selected a case study approach to find quantitative data using a scientific and empirical approach. This chapter describes the research design by introducing the conceptual framework that indicates the three data collection methods: field survey, consisting of physical measurement and questionnaire survey, and unobtrusive observation. These techniques are collectively regarded as the standard practice in assessment of outdoor thermal comfort. This chapter further describes the protocol to conduct field surveys and presents the relative information on the equipment devised during data collection. Ultimately, this chapter specifies the data analysis plan discussing the structure of data, data processing and archival, and analysis of thermal responses.

Chapter 5 describes the specifications of the three outdoor sites selected as the case study in this research. These sites are located in Melbourne's CBD which characterises typical urban education precincts in Australian cities. A standard classification put forward for urban temperature-related studies also applied to specify urban form corresponding to each study site.

Chapter 6 reports the research findings achieved from monitoring and measurement of thermal conditions, surveying users' thermal responses, and observations on usage pattern in the case studies. Accordingly, this chapter presents and compares the predictions of thermal comfort conditions versus actual users' thermal responses during the study seasons. By means of descriptive analysis, this chapter reports people's thermal responses in different seasons and sites, which then on the basis of inferential analyses explains how the survey users expressed their thermal satisfaction using different perceptual scales. Expanding on this information, the chapter further specifies the requirements of thermal comfort in case studies. The chapter also narrates the characteristics of participants' visits to the RUCC open spaces and outlines the corresponding usage pattern in relation to thermal conditions and the time of day.

Chapter 7 aims to find a possible meaningful relationship between different contextual factors and outdoor thermal sensations under various meteorological conditions via inferential statistics. The analyses provide an understanding on the impact level of contextual factors in the creation of perceptions. This chapter also presents the occurrence of thermal adaptation among the study population. **Chapter 8** discusses the outcome of the research presented in Chapters 6 and 7 with the view to elaborate on the findings and provide the reasoning for identified relationships. This chapter also explains the differences found in determination of thermal satisfaction between the assumptions of comfort standards and people's actual thermal perceptions using the multi-model theoretical framework presented in Chapter 4. **Chapter 9** presents the key findings of this study and relates them to the research questions. The chapter also discusses the limitations, the need for future studies and the contribution to the existing literature on thermal comfort.

CHAPTER 2: URBAN FORM, MICROCLIMATE AND ADVANCEMENTS IN THERMAL COMFORT

2.1 INTRODUCTION

The increase in urbanisation worldwide has transformed rural lands to urban areas with specific characteristics and issues. Among the issues identified to date, the interplay between microclimate, people's usage and urbanised areas have become a pressing topic in urban studies. This chapter begins with exploring the relationship between urban form, urban precincts, and surrounding meteorological conditions Subsequently, this chapter reviews the general knowledge and corresponding practice of thermal comfort. This review provides a brief outline of its origins, evolutionary development and the underpinning approaches established in the context of indoor conditions. The chapter also establishes the current principles of thermal comfort assessment as per the existing thermal comfort standards. These principles provide information on how to specify thermal comfort conditions using two approaches: heat balance theory and the adaptive approach. The sections allocated to these two approaches indicate the key concept of thermal adaptation, which includes three components: firstly, scales used to understand subjective thermal assessment; secondly, techniques for prediction of thermal comfort and; thirdly, analysis of human thermal responses in outdoor conditions. The analytical measures presented here are based on assumptions enshrined in thermal comfort standards and were the main platform to investigate the research hypothesis on the adequacy of thermal comfort standards.

2.2 URBAN FORM AND MICROCLIMATE

With the increase in urbanisation, urban researchers have directed the urban authorities' attention to its potential adverse consequences. One issue is the influence of the urban form on the local microclimate, which has been now excessively investigated in urban-human research (Oke 1982, Taha 1997, Santamouris 2013). A consensus exists on the impact of urban form and design on the urban microclimates (Arnfield 2003), thermal conditions (Oke 1982, Coutts et al. 2007a, Akbari and Rosel 2008) and human thermal comfort (Zacharias et al. 2004, Johansson 2006a, Steeneveld et al. 2011).

In general, urban environments experience a substantially different microclimate than those of rural areas (Oke 1982). The urban heat island (UHI) effect, which is a term used to describe this thermal differences, has intensified with the rising level of urbanisation (Unger 1999). Urban development is often accompanied with high density, urban consolidation, construction and development of infrastructure (Oke 1982). Unlike vegetated areas, urbanised surfaces have higher temperature due to the high capacity of heat absorption and low evapotranspirative cooling effect (Taha 1997). Urbanisation generates increased temperature in urban environments, leading to intense energy consumption, higher anthropogenic heat production and more greenhouse gas emissions that collectively contribute to the deteriorated thermal conditions (Oke 1982). Depending on many factors, including culture, demands, land use patterns and the typical local design, urbanisation follows different forms (Lilley 2009). Among many schools of thought on the definition for urban form, Hussain (2009 p. 188) describes it as "…*physical arrangement or structure of the town, its pattern of streets, building blocks, individual buildings, their different functions, densities and layout*". Urban form not only represents the identity of a particular part of a city but also determines the surrounding ecosystem, which in turn governs the dynamics of existing and developing relationships between built environment, thermal conditions and living creatures including urban residents. Therefore, in order to create sustainable and successful outdoor environments it is necessary to precisely predict, consider and react to different consequences emerging from the development of new urban forms.

2.2.1 URBAN PRECINCT AND DEVELOPMENT IN AUSTRALIA

One of the UN-Habitat (2009) recommendations to develop sustainable urbanisation is to minimise the urban sprawl is advocated as opposed to more compact cities. Jabareen (2006) compared different urban forms and stated that from an urban planning standpoint, the compact city is regarded as a sustainable urban form. The idea of compact city proposes city with higher density and diversity. Jabareen (2006) listed the sustainable features of four different urban forms reviewed in terms of density, diversity, mixed land use, compactness, sustainable transportation, passive solar design, and ecological design. These compact cities have taken the shape of urban precincts. A precinct is an outdoor place surrounded by the walls or other boundaries of particular built environments, or by an arbitrary and imaginary line drawn in its vicinity (Hussain 2009). Urban precincts give a sense of enclosure with different physical characteristics and focused activities. The formation of a precinct is considered an urban phenomenon, and in urban planning the term ''precinct'' is specified as an urban area with the distinctive character consisting of its internal closure and mobility. It can serve as a recreation precinct, residential precinct, education precinct, or entertainment precinct (Cullen 2007).

Australia is a sizeable continent with more than 75% of its areas recognized as remote and rural. The population mostly lives in several large state capital cities. Recent trends suggest development and redevelopment of the urban public spaces to urban precinct with the aim of minimising the adverse environmental, social, and economic consequences. Included in plans recommending this sort of urban development are higher density housing (Department of Sustianability and Environment 2004b), Guideline for Activity Centres (Department of Sustianability and Environment 2004a), Plan Melbourne (The State Government of Victoria 2014) and Melbourne 5 million @ 2030 (d'Argent 2012). Such policies outline the future directional growth of Australia's capital cities to confine the residential expansion, while ensuring population growth and infrastructure are considered in the boundary of urban growth (Forster 2006). In 2002, the Victorian Government issued the State Planning Policy Framework, called Melbourne 5 million @ 2030 specifically to accommodate 5 million people in Melbourne (Victorian Government 2008) on the basis of planning for sustainable growth. Its aim is to consolidate the Melbourne metropolitan region into a compact city in which urban development is purposefully concentrated in 100 densely mixed use activity centres (Forster 2006). City of Melbourne listed its distinct precincts and describes them as the "small pockets of the city with their own unique character and charm" (City of Melbourne 2012a).

The success of urban precincts in Australia has provided the impetus for further development of such areas across the country. Among others, the education precincts are of particular importance to the economy of Australia due to the advantages it has in providing global education. Based on more than 515,853 international student enrolments in 2012, Australia is among the top three countries providing the most educational opportunities for international students (Australian Education International 2013). Accommodating the educational spaces required for this number of students when there are shortages in spaces in the capital cities has necessitated consolidations and thus development of the university-centred precincts. These spaces are most likely to be the future form of the development in educational built environments in Australia. These newly developed precincts provide a learning framework to further understand the human place relationships particularly with reference to the impact of local meteorological conditions on human thermal comfort.

2.3 PRACTICE OF THERMAL COMFORT: MODELLING APPROACHES, MEASUREMENT, AND ANALYSIS

2.3.1 HEAT BALANCE THEORY: LABORATORY EXPERIMENTS

The heat-balance approach was primarily developed based on climate chamber experiments on 1296 Danish students (Fanger 1970) in steady-state conditions. The participants were required to judge their immediate thermal environment against the sensation scale whilst they were dressed in normal clothing and were exposed to different thermal conditions. The predicted mean vote (PMV) model developed by Fanger combines the heat balance theories and the physiology of thermoregulation to define comfort zones, which is regarded as acceptable for the majority of building occupants.

Fanger studied the parameters influencing the human body's heat balance whilst the body is close to neutral conditions. He found that only the sweat rate and mean skin temperature are the physiological processes involved in the regulation of the body's thermal conditions. To further understand the relationships between these factors and the activity level, he employed data from studies on college-aged students in different thermal conditions and activity level. Deriving these linear relationships, considering the results of other studies (Nevins et al. 1966, McNall Jr et al. 1967) and implementing some amendments according to people's thermal sensation votes, he developed a comfort equation that could predict comfort conditions for many building occupants in steady-state conditions (Fanger 1967).

Gagge et al. (1986) also introduced a two-node model known as the Pierce two-node model. Based on experiments conducted at J.B. Pierce Foundation Laboratory, Yale University, this model adopts the heat balance equation created by Stolwijk and Hardy (Gagge 1971). In this model the human body is divided into two concentric cylinders: the inner cylinder, that is body core, and the outer one, that is skin layer. These two cylinders possess average temperature of 37.1 ˚C and 33.1 ˚C, respectively. The model is adopted in the ANSI/ASHRAE Standard 55-2010: Thermal Environmental Conditions for Human Occupancy in the mould of thermal comfort index (ASHRAE 55 2010). Gagge's model was improved on, such as the development of new heat-balance models including the Munich Energy Balance Model for Individual (MEMI) (Höppe 1993).

With comfort standards, people's thermal perceptions otherwise known as people's thermal satisfaction are mostly investigated using four perceptual thermal scales: "thermal sensation", "thermal preference", "overall comfort", and "thermal acceptability". Emerging from these scales are the measures of thermal satisfaction including "thermal neutrality", "preferred temperature" and "acceptable thermal range". However, in some studies "personal tolerance", "thermal satisfaction", and "thermal sensitivity" were also used to characterise subjective assessment of thermal conditions. The standards, recommending the use of these scales in assessment of thermal comfort, postulate that people's thermal neutrality, drawing on thermal sensation votes, is the best representation of satisfaction with thermal environment. Therefore, the main goal of thermal comfort research is to find a temperature or thermal range that corresponds to those votes cast on the categories indicating thermal acceptance. The specifications of the scales and corresponding measures including their definitions are provided in Section 2.5.

2.3.2 ADAPTATION MODELS: FIELD SURVEYS

Drawing on field studies, the adaptive model considers human interaction with the environment. The core assumption of adaptive models is based on the following principle: *if a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort* (Nicol and Humphreys 2002, p. 564). These models account for parameters other than physical and physiological determinants of people's perceptions of thermal conditions. A number of researchers used the adaptation concept and a few of them are recognised as pioneers: Webb (1959), Auliciems (1981), de Dear et al. (1997), Humphreys and Nicol (1998) and McCartney and Nicol (2002).

Being the originator of the adaptive paradigm, Charles Web suggested that people in various geographical locations are adapted to the mean outdoor air temperature (Webb 1959). In the 1970s, Nicol and Humphreys (as cited in Nicol 1974) introduced the "regulatory feedback system" for occupants' thermal comfort according to which people are assumed to react to their surrounding thermal environment, which establishes the foundations of adaptive thermal comfort. Later, Auliciems (1981) suggested that besides outdoor air temperature, the combination of past and present thermal experiences, cultural and technical practices determine the thermal expectation. He also stated that the process of adaptation could consist of physiological, behavioural, psychological, and cultural components. Comparing the specifications of the two approaches (adaptive comfort vs. heat-balance approach), de Dear and Auliciems (1985) concluded that these two approaches are complementary rather than competing. Since then, several attempts were made to understand the similarities and discrepancies of these approaches with the view to finding the way to achieve thermal comfort. It is important to note that while the adaptive models highlight the role of human parameters in the assessment of thermal comfort they do not currently provide much insight into what thermal conditions are comfortable (satisfactory), other than a generalization that they match people's expectations (de Dear 2011).

As a comprehensive definition, adaptation is the process of gradually reducing the body's response to a stimulus, comprising all changes allowing the body's components a better chance to survive in existing conditions (Glaser 1966). de Dear et al. (1997) in the ASHRAE RP-884 report characterize the adaptation as all physiological processes of acclimatization along with behavioural and psychological changes undertaken by individuals to improve thermal conditions. Adaptation falls into the categories of acclimatization, habituation, and adjustment (Figure 2.1).

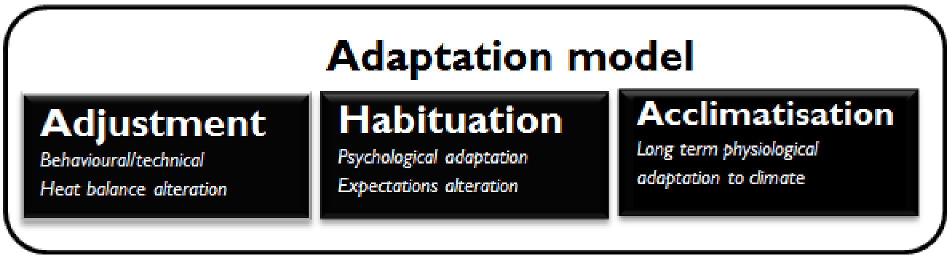


Figure 2.1 The components of the concept of thermal adaptation
Source: de Dear (1997, p. 6)

2.3.2.1 Physiological adaptation

Physiological acclimatization encompasses all biological modifying processes induced in an individual's body with the intention of gradual adaptation in response to the environmental stimuli (Humphreys 1975, Gonzalez 1979). For instance, the physiological response of the human body to a periodical exposure to hot conditions, within a certain number of the days, would change; particularly the sweat rate, which will increase and accelerate in accordance to the given stimulus. It is claimed that while it changes the thermal tolerance, physiological adaptation has no implications for comfort requirements (Brierley 1996, Parsons 2002). According to de Dear et al. (1997) physiological adaptation relies on two principles: genetic adaptation and acclimatisation. Genetic adaptation is linked to the genetic adaptability to the prevailing microclimate rather than acquired adaptability. Acclimatization relates to "vicissitudes" the physiological thermoregulation mechanism over a specific period against thermal-induced strains.

2.3.2.2 Psychological adaptation

Psychological adaptation describes the possibility of modifying the perceptions and reactions to maintain thermal comfort (Williams 1995) due to past experience and expectations (McIntyre 1980). The moderation in expectations is connected to the concept of habituation in psychophysics where frequent exposure to a stimulus mitigates the level of evoked response (Brager and de Dear 1998). The thermal expectation is a key concept to attain psychological adaptation. In his study on identification of requirements for a comfortable environment, McIntyre (1981) recognised the position of expectation in thermal comfort as "*a person's reaction to a temperature which is less than perfect will depend very much on his expectations, personality, and what else he is doing at the time*" (p. 201). According to the hypothesis of thermal expectation, following repeated exposure to changes in thermal conditions, individuals' expectations of those conditions could become more relaxed – even anticipatory of temporal changes (Fountain et al. 1996).

Figure 2.2 depicts the interrelationship among the psychological adaptation components. Among the three components of adaptation, psychological adaptation can best explain the discrepancy observed in the predicted thermal comfort and actual thermal comfort (Nikolopoulou et al. 2001). Therefore, an investigation of parameters leading to psychological adaptation can provide useful information on people's thermal perceptions, expectations, and preferences in urban outdoor environments. In the context of the outdoor environment, Nikolopoulou and Steemers (2003) suggest the basic psychological mechanisms which influence people's thermal judgement. As shown in Figure 2.2, these include naturalness, perceived control, the time of exposure, environmental stimulation, expectations, and experience.

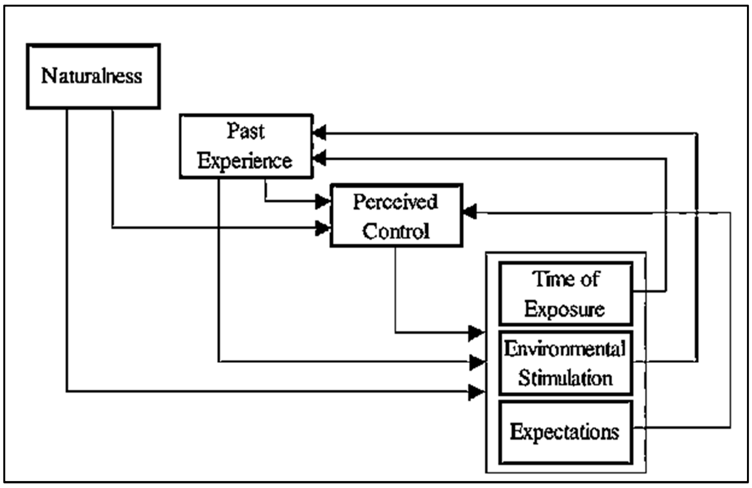


Figure 2.2. Interrelationship among different components of psychological mechanism in outdoor environments
Source: Nikolopoulou and Steemers (2003)

2.3.2.3 Behavioural adaptation

Behavioural adaptation or adjustment in thermal conditions specifies all modifications that an individual may undertake consciously or unconsciously to adapt to surrounding thermal conditions. This kind of adaptation is basically linked with a process in which alterations occur in heat and mass flux balance of the body. The process of adjustment begins when an individual experiences thermal dissatisfaction following exposure to a given thermal environment. Afterwards, an individual initiates adaptive actions to attain thermal comfort (Brager and de Dear 1998). The effectiveness of the adaptive actions taken by an entity depends on the available option which is known as "adaptive opportunity" (Baker and Standeven 1996, Nikolopoulou and Steemers 2003).

2.4 DIFFERENCES IN THE DETERMINATION OF THERMAL COMFORT FOR INDOOR AND OUTDOOR CONDITIONS

Due to the differences found between the nature of outdoor and indoor conditions, a procedure of assessing thermal comfort is required for outdoor spaces. Several scholarly reviews have been published on the difference in the attainment of thermal comfort between these two sets of conditions (Höppe 2002, Spagnolo and de Dear 2003, Johansson et al. 2014). These review studies suggest a segregation in the assessment of certain parameters impact on thermal comfort in each condition. The following sections highlight the differences between outdoors and indoors regarding the achievement of the human body's heat-balance, thermal expectations, and occupants' behaviour.

The way that body achieves heat balance differs in indoors and outdoors. While the steady state is possible in indoor conditions, its achievement is very rare outdoors. Höppe (2002) maintained that in real world conditions, steady state is not achievable even if people spend a while outdoors. This is due to transient weather conditions outdoor and spatial diversity producing varying meteorological conditions within an outdoor environment. The non-steady-state thermal conditions reactivate bodies' physiological and behavioural temperature regulatory mechanisms (de Dear 2011). The implication of these conditions is over/underestimation of thermal comfort conditions using steady-state- driven models. To date, advances in the development of non-steady-state models are yet to be effectively put into practice and subsequently experts still use steady-state models. A detailed review of shortcoming regarding the use of steady state-driven models is provided in Section 2.6.1.

The perception of thermal conditions in outdoors and indoors differs which suggests the application of indoor thermal comfort standards to outdoor spaces is inefficient (Potter and de Dear 2000). The main difference is that thermal expectations directly or indirectly influence people's thermal perceptions. Spagnolo and de Dear (2003) argued people expect to experience variable and sometimes adverse weather conditions outdoors which may make them feel more tolerant of weather conditions within a wider range. For instance, there are occasions in which people are willing to be voluntarily exposed to a less than ideal thermal conditions such as a beach resort where tourists preferred no change in current thermal conditions while indicating warm/hot thermal sensation (de Freitas 1985). Focusing on thermal expectations, this fact underlines the importance of psychological adaptation in thermal perceptions.

In addition to varying expectations, Höppe (2002) indicated that different patterns of adaptive behaviour and achieving heat balance could potentially lead to varying thermal perceptions in these two conditions. On this theme, Emmanuel (2005) observed that people indoors tend to wear light clothing, engage in lighter activities and are exposed to a relatively constant thermal environment longer than outdoors. These together differentiate the human body thermoregulations and accordingly thermal perceptions.

2.5 SCALES OF HUMAN THERMAL RESPONSES

As indicated earlier in this chapter, four perceptual scales explore the characteristics of people's thermal judgments. In comfort research, these scales represent different concepts and may not similarly characterise people's thermal perceptions (Brager et al. 1993). The difference between these indicators is explained by Spagnolo and de Dear (2003) who described the human thermal environment "*as a set of concentric 'zones' with thermal preference at its centre, flanked by a wider band of thermally comfortable conditions, which in turn may be ranked by wider bands of acceptable thermal conditions*" (p. 722). Also, the differences in thermal perceptions (Howell and Kennedy 1979, Revd 1996) and the missing relationship between thermal sensation and thermal preference

(Williamson et al. 1989) challenge the underpinning assumptions of thermal comfort theory drawn on thermal sensation (Andamon 2005). Of these scales, the thermal sensation scale and its categories are the basis of calculations used to specify comfort conditions (i.e. comfort temperature) as stated by thermal comfort standards.

2.5.1 THERMAL SENSATION

Thermal sensation is a judgement of immediate experience resulting from exposure to a set of parameters, forming a thermal environment. In effect, thermal sensation refers to sensory unconscious detection of environmental stimulation/information by thermal receptors in the skin. This scale is conceptually different from the notion of thermal comfort which is that condition of mind expressing thermal satisfaction. Instead, thermal sensation refers to the individual's evaluation of his/her thermal environment (Zhang and Zhao 2009). Following the same line of reasoning, Nakamura et al. (2008) contended that thermal sensation "*is utilized by the body to obtain information concerning the thermal condition of external objects or the environment, and it is evoked by signals from warm and cold receptors in the skin* (p.1897)". They did, however, indicate that thermal comfort "*is important for temperature regulation in that it drives an individual to search for the appropriate thermal environment or to make local alterations or postural changes to maintain normal body temperature*" (p. 1897). Table 2.1 shows and compares the categories of scales used to assess thermal perceptions.

Table 2.1. Thermal scales and corresponding categories typically used to assess thermal perceptions

	ASHRAE Thermal sensation	Overall comfort	McIntyre preference scale	Thermal acceptance
7(+3)	hot	very uncomfortable		
6 (+2)	warm	moderately uncomfortable		
5 (+1)	slightly warm	slightly uncomfortable	warmer	acceptable
4(0)	neutral	just right	no change	
3 (-1)	slightly cool	slightly comfortable	cooler	unacceptable
2 (-2)	cool	moderately comfortable		
1 (-3)	cold	very comfortable		

The thermal sensation vote (TSV) is judged on the ASHRAE 7-point scale (ASHRAE 55 2010) which is also endorsed in ISO 7730 (2006) and CEN (2007). The 7-point sensation scale ranges from "cold" (-3), "cool" (-2), "slightly cool" (-1) to "slightly warm" (+1), warm (+2) and hot conditions (+3) with zero in middle denoting the "neutral conditions". The reason for the widespread use of the "seven-point" version of thermal sensation scale as opposed to scales with less or more categories has been previously discussed (Miller 1956, Dawes 2008). For instance, Dawes (2008) argued the validity of responses obtained from Likert scales will improve when 5-point or 7-point scales are used instead of scales with limited categories. The author noted that the scales with more categories (e.g. 10 points) would not produce responses that are more reliable.

In accordance with comfort standards, the three central categories of thermal sensation scale constitute the main assessment to compute thermal acceptability (satisfaction). These three categories in fact represent people's acceptance vote on thermal conditions. The common contention in using this method is that the optimum (comfort) temperature accords to a neutral temperature derived from assigning that temperature at which most people voted for "slightly warm", "neutral" and "slightly cool". de Dear and Fountain (1994) suggested the use of mean thermal sensation vote (MTSV) instead of individual TSVs to reduce the effect size of individual difference. Thus, MTSV has been extensively used in thermal comfort studies to better describe the impact of thermal conditions on many people.

2.5.2 THERMAL PREFERENCE

Thermal preference is a primary measure of thermal satisfaction and elicited using the McIntyre preference scale (McIntyre 1982). This scale offers three choices to survey participants: "cooler", "no change" and "warmer". de Dear and Auliciems (1988) stated that thermal preference is a product of psychological adaptation derived primarily from thermal experience and expectation. It is also argued that the preference scale is an indirect measure of thermal acceptability when acceptability is assumed to be synonymous with votes casting "no change" in current thermal conditions (Brager et al. 1993).

2.5.3 THERMAL ACCEPTABILITY

Another scale used in comfort research is thermal acceptance and it is a binomial indication of thermal perception with "acceptable" and "unacceptable" as choices (Berglund and Gonzalez 1977). This is promoted in relevant standards as "personal acceptability" with two-category statement of "acceptable rather than unacceptable" and "unacceptable rather than acceptable" (ISO 10551 1995). This scale also has a version with four categories: "clearly acceptable, "just acceptable", "just unacceptable" and "clearly unacceptable" (Johansson et al. 2014). The scale serves to compute the acceptable thresholds of four environmental parameters (air temperature, relative humidity, wind speed and radiant temperature).

2.5.4 OVERALL COMFORT

Overall (general) comfort scale involves 7 categories which accord to the ASHRAE 7-point scale of thermal sensation (Schiller 1990). The overall comfort scale starts from "very uncomfortable" (1), "moderately uncomfortable" (2) and "slightly uncomfortable" (3) in the left side of scale; "just right" (4) in the middle; and ending with "slightly comfortable" (5), "moderately comfortable" (6) and "very comfortable" (7) on the right-hand side of the scale. In ISO 10551 (1995) this scale is known as "affective evaluation" containing four categories (comfortable, slightly uncomfortable, uncomfortable and very uncomfortable).

2.6 PREDICTION OF THERMAL COMFORT

As indicated earlier, the main aim of comfort research is to describe the thermal environment with reference to human thermal response. When human response is well associated to physical parameters known to impact on thermal comfort then a reliable prediction can be made to determine comfort conditions (Humphreys 1975). Modern human thermal comfort assessment largely hinges on the application of thermal indices, generally based on heat balance theories to predict thermal comfort requirements in steady state conditions. Calculation of thermal comfort is an assessment approach that characterises the level of comfort in a given thermal environment using meteorological parameters.

This approach, which is primarily premised on Fanger's (1970) steady-state heat exchange model, considers four environmental variables and two personal factors. These parameters can affect human heat balance and thus human thermal perceptions both indoor and outdoor (Macpherson 1973). As illustrated in Figure 2.3, the environmental variables include air temperature, relative humidity, wind speed, and mean radiant temperature. The two personal factors are clothing insulation and metabolic activity level. The collective effect of these variables is then calculated and expressed in the form of one thermal comfort index. Accommodating these variables in the steady-state heat balance models, indoor thermal indices were then generated to predict comfort conditions for a large group of people. The output of these indices is then equated to various levels of physiological thermal stress levels, which will delineate the extent of comfort/discomfort in the given thermal environment.

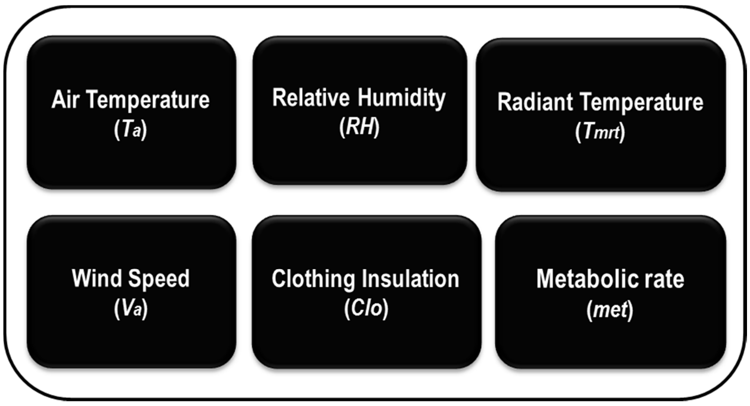


Figure 2.3. Six compartments of thermal comfort

2.6.1 DEVELOPMENT OF INDOOR THERMAL INDICES AND THEIR APPLICATION OUTDOORS: LIMITATIONS AND ADVANTAGES

As mentioned before, outdoor thermal comfort assessments are heavily based on indoor comfort research. In the absence of standards on the protocols for outdoor thermal comfort assessment, the same standards are loosely used in outdoor conditions.

However, despite a consensus on the feasibility of tentative use of indoor thermal comfort principles in outdoor environments, there are some important barriers hindering their full application. The complex nature of outdoor environment including dynamic environment, lack of climate control in outdoor, physical, socio-cultural adaptation of users are all identified as the cause of difficulty in using indoor assessment approach outdoor (Johansson et al. 2014). In virtue of these shortcomings and drawing on indoor thermal comfort models few outdoor-specific indices have been developed (Höppe 1999). While these indices share roughly the same basis with indoor indices, they consider physical parameter in a different way. Matzarakis and Amelung (2008) argued that "*these well-documented thermal indices have varying foci, but are essentially different combinations of the same set of important meteorological and thermophysiological parameters*" (p. 162).

In steady-state heat balance theories it is merely assumed that the four environmental variables- humidity (RH), wind speed (V_a), air and radiant temperature (T_a and T_{mrt}) and the two personal factors (level of activity and clothing insulation)- are the main factors that impact on the human body's thermoregulation. The indices use the steady-state heat balance models to predict thermal comfort wherein a person's body is assumed to stay at near to steady state conditions. However, there is some evidence questioning the validity of results caused by inadequacy of steady-state-driven indices applied in varying contexts including but not limited to culture, climate, and target population (Höppe 2002, Metje et al. 2008, Ng and Cheng 2012, Ruiz and Correa 2014). This conclusive evidence shows a degree of inconsistency between predicted and observed comfort. Thus, some studies have attempted to modify steady-state models used by these indices for further accuracy in predictions (Fiala 1998, Zolfaghari and Maerefat 2011, Chen and Ng 2011). Presented below are the main reasons reflecting shortcomings and limitations in steady-state based comfort models.

2.6.1.1 Attainment of steady-state conditions in outdoor spaces

Thermal comfort indices, being based on the steady-state models, could only produce the best results when an individual has reached thermal equilibrium conditions. However, the dynamics of thermal equilibrium vary between indoors and outdoors.

Some differences exist in the thermo-physiological dimensions of thermal comfort achievement outdoors versus indoors. In addition to typical differences between people occupying an indoor or outdoor setting (e.g. level of garment insulations and activity), a remarkable distinction is the time typically spent in these environments. Most users of outdoor spaces stay outside for a limited time (Höppe and Martinac 1998, Leech et al. 2002, Aljawabra and Nikolopoulou 2010) and hence barely reach steady state conditions. For this reason, the steady-state-based models tend to overestimate thermal discomfort (Höppe 2002). Thermal comfort under non-steady state situations primarily deals with rapid microclimate transients and noticeable changes in microclimate conditions, level of activity and clothing insulation within the course of minutes (Katavoutas et al. 2015). Höppe (2002) found that thermal steady state conditions are never reached after several hours in cold weather conditions, and may be attained after 30 minutes in warm conditions. ASHRAE 55 (2010) suggested that participants should reside in the space for more than 15 minutes; some outdoor studies even have suggested longer (e.g. 30 minutes) for outdoor environments (Höppe 2002, Xi et al. 2012). This particularly becomes an important concern when thermal comfort assessment is to reflect real life situations with a major proportion of people spending a limited amount of time outdoors. Given the general tendency of short stay outdoors, non-steady state models should ideally apply to outdoor environments and a differing assessing approach is required for comfort conditions indoors and outdoors.

2.6.1.2 Non-uniform conditions of outdoor spaces

Typical open spaces in cities, depending on spatial design and geometry, encompass different sub-areas with transient microclimate conditions. These transient conditions make users experience sometimes very different microclimate conditions, which influences their thermal judgement. For instance, a pedestrian entering a sunny segment within a few seconds from a shaded area does not perceive thermal conditions to be the same as he would under a direct hot sunlight for a longer time. Despite certain degrees of validity of steady-state models in the prediction of outdoor thermal comfort for users with time of exposure greater than 30 minutes, there are some situations wherein these models are not quite applicable (Höppe 2002). This may cause overestimation of thermal discomfort (Höppe 2002) and the role of thermal history and acclimatization is simply neglected within non-uniform ambient conditions in such models.

2.6.1.3 Usability of alternative models: dynamic models

The procedures employed to enhance the usage of alternative to steady state models in thermal comfort assessment are yet to be empirically developed. Few studies have attempted to develop dynamic models to account for transient conditions and predict thermal comfort in such situations (Fiala 1998, Chen and Ng 2011, Katavoutas et al. 2015). However, these models are found to be highly complex and are technically applicable to few number of people as there are lots of prerequisite requirements and logistics procedures prior to assessing thermal comfort (Katavoutas et al. 2015).

2.6.1.4 Limitations in accounting contextual factors

Besides the parameters directly related to the thermal conditions, contextual factors are found to have a key role in assessment of thermal comfort; therefore, it is believed that the current assessing models should account for them (de Dear and Brager 1998). These contextual factors particularly in outdoor environments influence people's thermal expectations and thus thermal perceptions to a larger extent. Although current comfort models account for adaptive behaviours (e.g. level of activity and clothing), and the adaptive approach considers adaptation by integrating outdoor temperature in calculations (Nikolopoulou and Steemers 2003, Knez et al. 2009), a widely accepted and user-friendly thermal comfort index is yet to be developed to remove limitations associated with inclusion of such factors in assessment of thermal comfort both indoors and outdoors.

2.6.1.5 Altered thermal expectations in outdoor spaces

Thermal preference and acceptability of open spaces are quite different compared to those in indoor conditions. People who intend to visit outdoor spaces will expect to face highly variable and more severe microclimate conditions. This expectation makes people show more tolerance against thermal conditions and they typically express a higher degree of thermal acceptability which is at odds with predictions of steady-state models which are likely to overestimate thermal dissatisfaction (Höppe 2002, Krüger and Rossi 2011). The problem with these models is that they offer no information on how to integrate the expectations into the thermal comfort standards (Fountain et al. 1996). Potter and de Dear (2000) postulated that the sensations of outdoor thermal conditions are different from those indoors; consequently, they cast doubts on the applicability of indoor assessing techniques to outdoor settings.

Furthermore, on some occasions people prefer to be voluntarily exposed to certain weather conditions, which may be considered as a thermal stressor in normal circumstances. To illustrate, in a study on people visiting beaches (de Freitas 1985) it was reported that despite their thermal judgment indicating the warm side of TSV scale, they preferred warmer conditions. The other issue faced by thermal comfort studies with steady state models is the varying comfort requirements in different seasons. While indoor thermal conditions provide relatively stable thermal conditions with a limited variation with occupants in different seasons, outdoor spaces engender highly variable thermal conditions throughout a year. Therefore, it is possible that people enjoy sudden changes in weather conditions outdoors after a certain prolonged type of thermal condition; this condition is related to the concept of alliesthesia (Cabanac 1971). Alliesthesia reflects people's thermal pleasure in having thermal conditions that are different to what they currently experience. In addition, it is not unusual that people who mostly spend their time in buildings enjoy outdoor thermal conditions, and this results in thermal satisfaction. The steady-state-driven models, however, do not capture these thermal expectations and previous thermal experiences.

As highlighted before, in spite of attempts to develop non-steady state (dynamic) energy balance models (Fiala 1998, Katavoutas et al. 2015) there are no universally accepted indices to overcome such shortcomings and limitations. There are a few issues on how to develop and apply non-steady state (dynamic) models as follows:

- Unlike indoor conditions where a minimum time is determined for reaching steady state conditions in standards (ASHRAE 55 2010), it is arduous to deal with scenarios emerging from the use of dynamic models in outdoor conditions when the time spent outdoors is linked to thermal perception prediction;

- It is arduous to measure the effect of previous thermal history on thermal sensation despite the noticeable difference it may make (Salata et al. 2016); for instance, it is not easy to know whether a subject was in an air conditioned room or otherwise prior to stepping outdoors;
- Association of predicted thermal discomfort with cold stress related mortality is difficult due to the process of thermal adaptation to cold weather conditions that is not accounted for by steady state models.

2.6.1.6 Rationale for using steady state models and capacity to improve

Using indices based on steady-state models to predict thermal comfort is still the most effective method in comfort research indoors and outdoors (Johansson et al. 2014). Their usage allows for comparative evaluation of thermal comfort requirements between various contexts, users, and climates. With some level of uncertainties these indices have produced the most reliable results according to others studies (Lin et al. 2010, Mahmoud 2011). Unlike the dynamic models that are highly labour and cost intensive (Bröde et al. 2012a) these indices are better at predicting outdoor thermal comfort for a large number of people due to less complexity in calculations and predictions of comfort. As the steady-state models are relatively more user-friendly they can be easily used and interpreted by experts from other disciplines including biometeorology, urban designers and urban and regional planners seeking to develop plans for open spaces using information derived from thermal comfort assessment (Höppe 1999). Overall, considering the limited options made available to thermal comfort experts and practitioners, these indices are currently the best predictors of people's thermal perceptions in outdoor spaces particularly in transversal assessments.

While some efforts have been made to improve the accuracy and validity of results produced by these indices, linking predicted temperature values to people's mean thermal votes via regression models can lead to some improvements. Regression analysis can account for some contextual factors mediating people's thermal sensations; it also provides a model that is specific to the conditions of the study. Drawing on mean thermal responses, these models (i.e. steady state heat balance) can provide good insights into the requirements of thermal comfort in outdoor spaces but are limited to the contextual conditions (Höppe 2002).

2.6.2 OUTDOOR THERMAL COMFORT INDICES

2.6.2.1 Physiological equivalent temperature (PET)

The physiological equivalent temperature (PET) is defined as "*the air temperature at which, in a typical indoor setting (without wind and solar radiation), the heat budget of the human body is balanced with the same core and skin temperature as under the complex outdoor conditions to be assessed*" (Höppe 1999, p. 1). PET was originally based on the Munich Energy-balance Model for Individuals (MEMI) in 1987 and is technically linked to the Gagge's two-node model parameters (Höppe 1999). The theory underpinning this index is to transfer the actual thermal conditions in an equivalent indoor setting, where a similar thermal perception is assumed, and therefore considered to be applicable in outdoor conditions (Matzarakis and Amelung 2008). Several advantages are defined for using PET to assess of outdoor thermal comfort. Functioning in various climates, it has become an attractive tool and a universal thermal index. It also allows researchers to assess year-round weather conditions, due to its applicability in various seasons. Being expressed in ˚C unit, PET is much easier to be exploited by researchers and practitioners such as urban planners and government policy-makers (Honjo 2009, Ren et al. 2011).

PET has been widely used in outdoor thermal comfort studies (Johansson et al. 2014) and has been recommended in a guideline called German VDI 3787 (2008). The widespread use of PET allows researcher to perform cross comparisons between requirements of thermal comfort in different contexts. The comparative evaluations assist in better understanding the role of contextual factors when documenting people's thermal judgements. For the reasons mentioned above, PET has been adopted in many recent studies to assess outdoor thermal conditions. Table 2.2 exhibits the frequency of usage of different indices including PET across the seminal comfort studies in outdoor settings.

Table 2.2. Summary of studies assessing thermal comfort in outdoor settings

Country	City	Climate (Köppen classification)	Climate symbol	Thermal indices used	Reference
Australia	Sydney	Humid subtropical	Cfa	PET, ET*, OUT-SET*	Spagnolo and de Dear (2003)
	Melbourne	Oceanic climate	Cfb	PET, OUT-SET*	Kenawy and Elkadi (2013)
	Melbourne	Oceanic climate	Cfb	PET	Lam et al. (2016)
Brazil	Curitiba	Mesothermic, humid subtropical	Cfb	PET	Krüger et al. (2011)
Canada	Montreal	Humid continental, mild summer	Dfb	ET*	Stathopoulos et al. (2004)
China	Guangzhou	Humid subtropical	Cfa	SET	Xi et al. (2012)
	Hong Kong	Humid subtropical	Cwa	PET	Ng and Cheng (2012)
	Tianjin	Cold temperate	Dwa	PMV, PET, UTCI	Lai et al. (2014a)
Egypt	Cairo	Desert arid	BWh	PET	Mahmoud (2011)
Germany	Kassel	Maritime temperate(Oceanic)	Cfb	PET	Nikolopoulou and Lykoudis (2006)
Greece	Athens	Mediterranean	Csa	PET	Nikolopoulou and Lykoudis (2006)
	Tinos	Mediterranean	Csa	PET	Andreou (2013)
Hungary	Szeged	Maritime temperate (Oceanic)	Cfb	PET	Kántor et al. (2012a)
Israel	Yotvata	Desert arid	BWh	PMV, DISC	Becker et al. (2003)
Italy	Milan	Maritime temperate(Oceanic)	Cfb	Budget	Picot (2004)
Japan	Matsudo	Humid subtropical	Cfa	PET	Thorsson et al. (2007a)
Malaysia	Putrajaya	Tropical rainforest	Af	PET	Makaremi et al. (2012)
Portugal	Lisbon	Mediterranean	Csa	PET	Oliveira and Andrade (2007)
				PET	Andrade et al. (2011)
Singapore	Singapore	Tropical rainforest	Af	TOP	Yang et al. (2013a)
Sweden	Gothenburg	Maritime temperate (Oceanic)	Cfb	PET	Eliasson et al. (2007)
				PET	Thorsson et al. (2004b)
Switzerland	Fribourg	Maritime temperate (Oceanic)	Cfb	PET	Nikolopoulou and Lykoudis (2006)
Syria	Damascus	Dry, steppe	BSk	PET, OUT_SET*, ET*, and PMV	Yahia and Johansson (2013)
Taiwan	Chiayi	Humid subtropical	Cwa	SET	Lin et al. (2011)
	Taichung	Humid subtropical	Cwa	PET	Lin (2009)
					Lin et al. (2011)
	Yunlin	Maritime temperate (Oceanic)	Cwa	PET	Lin et al. (2011)
United Kingdom	Birmingham	Maritime temperate(Oceanic)	Cfb	UTCI	Havenith et al. (2012)
	Cambridge	Maritime temperate (Oceanic)	Dfa	PMV	Nikolopoulou et al. (2001)

Glasgow	Maritime temperate (Oceanic)	BSk	PET, THSW	Krüger et al. (2013)
Sheffield	Maritime temperate (Oceanic)	Cfb	PET	Nikolopoulou and Lykoudis (2006)

Source: adapted and modified from Johansson et al. (2014)

PET values are calculated using Rayman Software package 2.1 (Matzarakis et al. 2007). Rayman which was developed according to the German Engineering Society guideline (VDI 3787 2008) requires certain environmental variables to calculate PET, including T_a, RH, cloud coverage, air transparency, time and date of the experiment, albedo coefficient and solid angel ratio (Thorsson et al. 2007a). The level of activity and clothing insulation are assumed to be constant values. However, the Clo values differ in warm and cool seasons. Höppe, the developer of PET, indicated that variation in values of Clo and met will not result in considerable differences in PET output and will also not limit its applicability (Höppe 1999).

2.6.2.2 Outdoor standard effective temperature (OUT-SET*)

The outdoor standard effective temperature (OUT_SET*) thermal index is an extension of standard effective temperature (SET*) (Pickup and de Dear 2000). SET is defined as the "*temperature of an isothermal environment with air temperature equal to mean radiant temperature, 50 % relative humidity, and still air ($v<0.15ms^{-1}$) in which a person with a standard level of clothing insulation would have the same heat loss at the same mean skin temperature and the same skin wetness as he does in the actual environment and clothing to the SET for sedentary activities*" (Parsons 2003 p. 212). Similarly, OUT-SET* considers the same four environmental variables (T_{mrt}, V_a, RH, and T_a) and the two personal factors (*Clo* and met).

Unlike PET this index is not widely used in outdoor thermal comfort studies (Johansson et al. 2014), and its values are not broadly calibrated for various climate conditions. This could be related to ease of computation of PET through a software package (Rayman) and multiple usage of PET in different domains including urban meteorology. One good example of OUT-SET* usage was a study carried out in the subtropical climate of Sydney, Australia (Spagnolo and de Dear 2003). The authors inferred that OUT-SET* had a better prediction capacity compared to other thermal indices. Other studies compared its prediction ability to that of other indices (Lin et al. 2011, Xi et al. 2012, Yahia and Johansson 2013, Tsitoura et al. 2014, Coccolo et al. 2016).

2.6.2.3 Universal thermal climate index (UTCI)

The Universal Thermal Climate Index (UTCI) was developed in the late 1990s by a research team consisting of experts from different disciplines which received support from International Society of Biometeorology (ISB) and the World Meteorological Organization (WMO) (Jendritzky et al. 2001). The following goals were established to improve UTCI:

- Applicability to the whole extent of heat exchange in terms of thermo-physiology
- Conformity to all climatic conditions, as well as seasons and scales.
- Applicable to human biometeorology such as weather forecasting, plotting region-wide and worldwide bioclimatic maps, and climatic change studies.
- Being personal factor-independent, i.e. calculated without need of knowing individuals' gender, age, activity, etc.

UTCI is characterised as the reference air temperature (air temperature equates to Tmrt, wind speed =0.5 m/s at 10 m, relative humidity=50% up to a constant water vapour pressure of 20 hP_a and metabolic rate = $135 W \cdot m^{-2}$) that imposes the same thermal strain as the real-world conditions. This index is built on the multi-node dynamic thermos-physiological UTCI-Fiala model (Fiala et al. 2001). This model determines the effect of the thermal environment on the human body (for entire body and individual compartments) over a wide range of meteorological conditions and is validated using measured data (Coccolo et al. 2016). This multi-node model consists of 12 body compartments holding 187 tissue nodes. The UTCI-Fiala model computes the heat exchange within the body skin surface, and the heat transfer within the environment (in the forms of convection, evaporation, radiation, and respiration) and thermoregulatory reaction of the central nervous system.

This model was then completed using an adaptive garment model. Clothing insulation is automatically computed as a function of the actual air temperature and wind speed, using this clothing model (Fiala et al. 2012). Despite recent developments in the UTCI, there is a growing interest in its application in different climate zones. However, different quantities of this index are to be calibrated regarding different climate zones. For instance, Błazejczyk et al. (2010) suggested a classification of thermal stress (10 categories) defined over a range of UTCI quantities for European people. Figure 2.4 depicts the operational procedure of UTCI for assessing outdoor thermal comfort.

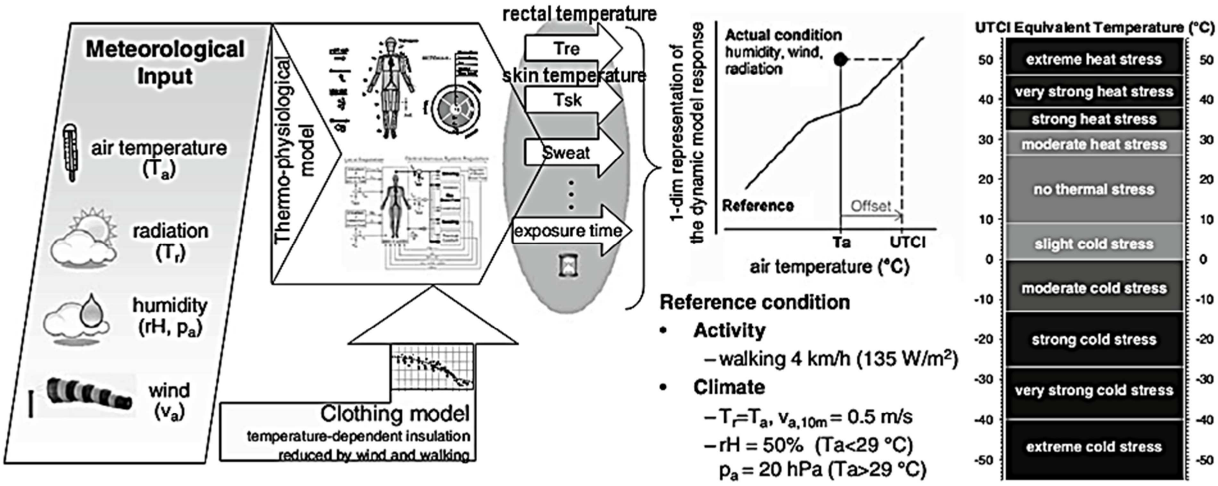


Figure 2.4. The schematic diagram of UTCI assessment
Source: Havenith et al. (2012)

Two procedures exist to calculate UTCI temperature with varying levels of complexities:

a. The complex procedure drawing on the UTCI-Fiala model integrated with the UTCI clothing model (Fiala et al. 2012). This method is time-consuming and requires expert knowledge has produced the satisfactory predictions (Psikuta et al. 2012). Considering the complexity of applying UTIC-Fiala in real-world conditions, this method may not fulfil the concerns of architects, urban planners, designers, etc., who do not have a broad knowledge of human physiology. Therefore, the second method is probably more practical as it is more user-friendly.
b. more simplified alternative that does not require to run the UTCI-Fiala physiological model(Bröde et al. 2012a). This procedure involves looking up tables of pre-defined UTCI quantities for all associated combinations of climate factors and a polynomial regression equation determining the index quantity over the similar associated climate combinations (Bröde et al. 2012b).

2.7 ANALYSIS OF HUMAN THERMAL RESPONSES: THERMAL NEUTRALITY, PREFERRED TEMPERATURE, AND COMFORT (ACCEPTABLE) THERMAL ZONE

2.7.1 THERMAL NEUTRALITY

Thermal neutrality denotes thermal conditions where a maximum percentage of occupants feel a temperature neutral. Drawing on this concept it is possible to calculate neutral temperature which is a thermal point wherein thermal recipients feel neither cool nor hot (ASHRAE 55 2010). The computation of neutral temperature in orthodox comfort research has become a primary goal because it is assumed to refer to comfort temperature. There are two analytical techniques to calculate neutral temperature, “regression analysis” (McIntyre 1978) and “probit analysis” (Ballantyne et al. 1977). The regression of mean value of thermal sensation over a range of temperature values yields an equation that defines the neutral temperature and anticipates the average of thermal responses at each temperature (Humphreys 1975). This equation indicates the best relationship between the mean subjective and the predicted thermal comfort. Accordingly, the neutral temperature is obtained by solving for zero in this regression equation.

The alternative method is to apply probit analysis to respondents’ TSVs. In this analytical method, the TSV scale categories are split into two levels: “warmer than neutral” and “cooler than neutral”; and the votes on neutral are evenly divided between these two levels. The intersection between the two resultant curves will predict a neutral temperature for the target population. The full procedure of this method is presented in Ballantyne et al. (1977).

2.7.2 PREFERRED TEMPERATURE

Preferred temperature is another measure of optimal thermal conditions in comfort research; it is also referred to as optimum temperature (McIntyre 1978). As per definition, preferred temperature is a temperature at which a majority of people prefer "no change" in the current thermal environment. Similar analyses on neutral temperature can apply thermal preference scale to compute preferred temperature. A temperature at which the probit curves of "change to lower temperature" and "change to higher temperature" cross is the preferred temperature. While it is not so unusual to interchangeably interpret neutral and preferred temperature as comfort temperature, it is argued that these two comfort indicators are not necessarily similar (McIntyre 1978, de Freitas 1985, Humphreys and Hancock 2007). The conceptual differences between these two measures induced ambiguity in the determination of thermal comfort. While standards advocate the assumption of equality between neutral temperature and thermal satisfaction, field studies proved that preferred temperature is sometimes a better representative of satisfactory/acceptable thermal conditions (Brager et al. 1993).

2.7.3 COMFORT ZONE: ACCEPTABLE THERMAL RANGE

Sometimes deducing people's thermal satisfaction at a single given temperature is arduous, thus, the concept of acceptable thermal range (comfort zone) was introduced into comfort literature (Rohles Jr and Nevins 1968). A range of thermal conditions is referred as acceptable when a considerable number of people perceive it as so. According to ASHRAE 55 (2010) acceptable thermal conditions should be acceptable to at least 80% of people in typical conditions. In other words, a thermal range in which only 20% of people are thermally dissatisfied is assumed to be the comfort zone.

There are two ways to determine the acceptability of thermal conditions: direct and indirect approaches. In the direct approach participants are simply asked for their opinions on the thermal variables being acceptable or otherwise. Whereas, in the indirect approach, the basis of calculation is the equivalence of three central categories with TSV scale (i.e. neutral, slightly cool, and slightly warm). The latter is mostly used in comfort studies both indoor and outdoor. However, its validity is under question particularly by studies carried out in outdoor settings (Lai et al. 2014a, Huang et al. 2016). Lai et al. (2014) stated that the application of the three TSV central categories to define the thermal acceptability is problematic. Huang et al. (2016) argued that "*acceptable thermal conditions for an outdoor space are in disputes, unlike those of an indoors pace that is reasonably well-established*" (p.238). The authors therefore developed an indicator, based on the attendance data in the study site instead of the TSV-based protocol, to define outdoor acceptable thermal range.

2.8 SATISFACTION WITH OUTDOOR THERMAL ENVIRONMENT

The orthodoxy of comfort following the engineering research carried out to date indicates that comfort is the product of a direct relationship between bodies and physical surrounding of a built environment (Andamon 2005). The comfort research drawing on physiological aspect of comfort specified that thermal comfort conditions are governed by three processes: biological conditions of occupants, thermal attributes of the environment and the method whereby heat is exchanged in the environment (Cooper 1982). These three processes are largely used in thermal comfort standards and corresponding comfort modellings to determine what is a satisfactory environment.

Satisfaction with thermal environment both indoor and outdoor, however, is not limited to the thermal attributes of a space. Indeed, comfort is a complex subjective judgement closely tied with not only physical and physiological parameters but also with psychological and social aspects that are sometimes arduous to evaluate (Williamson et al. 1989, Johansson et al. 2014, Shin 2016). Environmental satisfaction involves the subjective assessment of the objective qualities of a given environment, indicating how much the given environment fulfils the expectations and needs of the occupants. As the individual's expectations and needs rely on their value system in relation to their life stages as well as their goals and purposes for the given space, one's satisfaction with the environment is not easy to decontextualize and objectively assess (Shin 2016).

Consequently, although understanding is increasing in recent years about the role of factors other than thermal in the development of subjective sensations, comfort as a physiological condition continues to be the foundation for linking the physical parameters of an environment with the thermal state of occupants. As a result, at the current stage, determination of a satisfactory environment mainly hinges on both thermal and contextual factors that influence the human body thermoregulation.

Furthermore, it is of paramount importance to discern and examine which measure of comfort used in comfort assessment studies best represents the satisfaction with the thermal environment. As discussed above there are continuing debates on the suitability of typical comfort indicators (Williamson et al. 1989, Humphreys and Nicol 2004, Shin 2016). Due to the complex nature of "comfort" it is also required to precisely re-define the concept of comfort and establish its position in the context of "thermal satisfaction". In this regard Shin (2016) contended *that "...while both the constructs of satisfaction and comfort have been used equally widely in environmental design research as general indicators of building success, they were founded upon clearly different worldviews with different philosophical assumptions behind them, due largely to the scholarly backgrounds of the researchers who investigated each construct"* (p. 19).

2.9 THERMAL COMFORT STANDARDS

Three international organisations develop standards outlining the minimum requirements for achieving thermal comfort indoors. These include ASHRAE standard 55, CEN Standard EN 15251, and ISO 7730. These standards recommend protocols for assessment, modelling, measurement, and analysis of thermal comfort conditions. These standards focus on thermal neutrality (neutral temperature) which is assumed to best characterise the acceptable relationship between an individual and its surrounding thermal environment. The cornerstone of this assumption suggests that "neutrality" corresponds to thermal satisfaction and its application is extended to consider all biophysical conditions (Parsons 2003). Conventionally, engineering research established the basis of thermal comfort standards using the direct relationship between environmental and personal factors and comfort perception.

All these standards adopted the PMV/PPD index as the basis for specifying the standard for temperature control or thermal comfort. Adaptive models as a supplementary component were later added to comfort standards to overcome the shortcomings related to rational models and the role of contextual factors. In this regard, classifying comfort standards into two categories (i.e. those that standardise a methodology and those that specify good practice), Nicol and Humphreys (2002) contended that adaptive comfort modelling is mostly useful in the later type. Among the standards mentioned above only ASHRAE Standard 55 and CEN Standard EN 15251 have incorporated evaluative methods based on an adaptive approach. All the above-mentioned standards are subject to continuous review. As indicated before, in the absence of standards on the assessment of outdoor thermal comfort (Johansson et al. 2014), researchers evaluating human thermal comfort outdoors take advantage of the principles of these standards primarily developed for indoor conditions.

2.9.1 ANSI/ASHRAE STANDARD 55: THERMAL ENVIRONMENTAL CONDITIONS FOR HUMAN OCCUPANCY

The ASHRAE Standard was developed by the American Society of Heating Refrigerating and Air conditioning Engineers (ASHRAE 55 2010) and accredited by the American National Standards Institute (ANSI). The Standard is largely referenced throughout North America, South Asia, and Australia (Daniel et al. 2015). ASHRAE 55 was first published in 1966, and from 2004 has been periodically updated by a technical committee consisting of industry experts and academic scholars. Standard 55 was rewritten in 2010 with the focus on applying the Standard by practitioners and employing clear and applicatory language (ASHRAE 55 2010); its latest edition was published in 2013. The main objective in this standard is to determine the combinations of indoor thermal environmental (Ta, RH, V_a, and T_{mrt}) and personal factors (Clo, met) that create an acceptable thermal condition for a majority of occupants within a space. In the 1990s, a revision was made to ASHRAE 55 to accommodate adaptive comfort theory emerging from the findings of a research project (i.e. developing an adaptive model thermal comfort and preference) dealing with occupants of air conditioned and naturally ventilated buildings (de Dear et al. 1997). This revision proposed an alternative method for specifying acceptable thermal conditions in naturally conditioned indoor spaces with respect to outdoor ait temperature. It also reviewed the advantage of using adaptive opportunities to achieve thermal comfort including operable windows (de Dear and Brager 2002).

ASHRAE 55 recommends two classes of field investigation (i.e. Class I and II) out of three identified in comfort research (Brager and de Dear 1998). In these two classes, all physical variables (T_a, RH, V_a, T_g) necessary for calculation of steady-state based thermal comfort conditions are measured at the same time. To be more specific, in Class I three heights of measurements are considered for different sensors; whereas in Class II the measurement height is most likely to be similar. Class III of field investigation is designed for simple measurement of indoor T_a and probably RH at one height (Brager and de Dear 1998). Linking the three central categories of thermal sensation scale to acceptable thermal conditions, this standard specifies the comfort ranges for indoor conditions resulting from 80% acceptability; these acceptable thermal ranges include 23 ˚C to 26˚C (summer) and 20 ˚C to 23.5 ˚C (winter).

2.9.2 ISO 7730: MODERATE THERMAL ENVIRONMENTS- DETERMINATION OF THE PMV AND PPD INDICES AND SPECIFICATIONS OF CONDITIONS FOR THERMAL COMFORT

Drawing on the PMV/PPD, International Organisation for Standardization (ISO) 7730 considers body thermal sensation and local thermal discomfort caused by draughts (Fanger 1970, Olesen 1985). The focus of this standard is on offering a protocol for predicting thermal sensation and percentage of discomfort (thermal dissatisfaction) among individuals being exposed to moderate thermal environments, and to determine acceptable thermal environment (ISO 7730 2006). The PMV/PPD predict the mean value of thermal votes of a large group of people on TSV scale and binomial scale of "acceptable" or "unacceptable". ISO 7730 suggests that comfort conditions feature PPDs lower than 10% per the criteria of PMV falling between 0.5 and -0.5. It also presents methods for evaluating of local discomfort caused by draughts, asymmetric radiation, and temperature fluctuations. Olesen and Parsons (2002) argued that while application validity of PMV/PPD is often supported under laboratory circumstances, the field studies using this method have produced mixed results both in its favour or otherwise. It is also indicated that this method enshrined in this standard is mainly applicable to sedentary occupants wearing light clothing with thermal sensation of the whole body being close to neutral.

2.9.3 CEN STANDARD EN 15251: INDOOR ENVIRONMENTAL INPUT PARAMETERS FOR DESIGN AND ASSESSMENT OF ENERGY PERFORMANCE OF BUILDINGS- ADDRESSING INDOOR AIR QUALITY, THERMAL ENVIRONMENT, LIGHTING AND ACOUSTICS

CEN STANDARD EN 15251 seeks to establish environmental input parameters for non-industrial buildings for design and energy performance calculations without prescribing design methods (CEN 2007). Formulated by CEN/TC 156WG12 (Olesen 2007), EN 15251 focuses on assessing methods for long term evaluation of indoor environment from calculations or measurement. Similar to ASHRAE 55 (2010), this standard accounted for the specific expectations of occupants derived from the findings of a research project called Smart Control and Thermal Comfort project (SCATs), commissioned by the European Commission (McCartney and Nicol 2002). This standard also entails an adaptive comfort component but limited to only five western European countries. The applicability of this standard is extended to include non-industrial buildings where the criteria for indoor environment are regulated by human occupancy and where production and related processes do not largely influence the indoor environment (Taleghani et al. 2013) .

2.10 CRITICISM AND CHALLENGES OF USING THERMAL COMFORT STANDARDS

Several experts in the field of thermal comfort have questioned the applicability of these standards in various contexts (Olesen and Parsons 2002, Humphreys and Hancock 2007, Taleghani et al. 2013). These scholars have argued that assumptions enshrined in the existing standards are not adequate for specifying thermal comfort requirements that represent real-world conditions. They have emphasized the necessity for revising the 'philosophy' that forms the comfort standards, which was the stance of the adaptive approach to thermal comfort (Williamson et al. 1989, Humphreys and Nicol 1998, Brager and de Dear 1998, Shove 2003). This necessity has emerged from the fact that the current thermal comfort assessment methods based on heat-balance theory might not be adequate to reflect people's thermal comfort requirements. The challenge in the process of revision is the redefinition of "contemporary meaning and expectations of comfort" (Shove 2003).

In indoor thermal comfort research most criticisms of the application of these standards were expressed by advocates of the adaptive models of thermal comfort (Auliciems 1981, Humphreys and Nicol 1998). These criticisms particularly focused on the lack of consideration of psychological aspects of adaptation that could influence people's expectations and thermal preference. Brager and de Dear (2001) stated that these standards have systematically ignored the significant role of culture, climate, and society in comfort by considering them as secondary. In addition, in outdoor thermal comfort, the applicability of the standards is under question. Some criticisms related to application of indoor standards outdoors relates to differences in these two contexts affecting thermal expectations, preferences and thus perceptions (Section 2.10). By and large, the criticisms of these standards are rooted in three issues: the failure to consider the effect of contextual factors on human thermal comfort, uncertainties about use of thermal responses recommended in standards when interpreting actual thermal comfort, and the inability to differentiate thermal comfort requirements for individuals under steady-state and non-steady state conditions (Höppe 2002).

2.11 SUMMARY

Thermal comfort is developed to assess thermal conditions in the light of human health and well-being and energy consumption. This concept employs two approaches to assess thermal comfort: heat-balance model and adaptive paradigm. While the former is involved in calculation of thermo-physiological factors to predict thermal comfort, the latter aims to tie human parameters to the concept with the view that a person is an active recipient of environmental stimuli. The prediction of thermal comfort involves measuring environmental variables and personal factors, which are collectively expressed as a thermal comfort index. While the principles of predicting thermal comfort are built on the indoor studies, a segregation is suggested for outdoor thermal comfort assessment due to the differences in the two conditions. This segregation was also identified in thermal adaptation where the different pattern of adaptation can take place. Nonetheless, the assessment of outdoor thermal comfort still follows the recommendations developed for indoor standards. The widespread application of these standards, however, has been extensively under question. The next chapter critically reviews the assessment of thermal comfort using methods enshrined in the comfort standards.

CHAPTER 3: ASSESSMENT OF OUTDOOR THERMAL COMFORT

3.1 INTRODUCTION

The main objective of this chapter is to critically review the literature on the assessment of outdoor thermal comfort. It also identifies the key considerations and gaps in the literature that have facilitated the research rationale. The review looks at the importance of assessment of outdoor thermal comfort, the challenges it has faced and applicability of existing comfort standards (incl. models) in contemporary outdoor thermal comfort research and its linkage to use of outdoor spaces. These discussions lead to analytical evaluation of the role of contextual factors in the development of people's thermal perceptions. This evaluation generates an understanding of interaction dynamics of thermal conditions, people's subjective thermal assessments and various modifying factors (individual, social, physical, psychological and policy and standards) which can also explain why there is a mismatch between observed and predicted thermal comfort conditions in comfort research. This chapter presents the findings on outdoor thermal comfort research in Australia with the aim to understand the comfort requirements in conditions similar to the context of this study.

3.2 THE IMPORTANCE OF THERMAL COMFORT ASSESSMENT IN OUTDOOR SPACES

As indicated in Chapter 2, the rapid growth of populations and migrations from rural to urban areas has caused an intensive urban sprawl worldwide. Urban sprawl is often accompanied by dense housing, urban consolidation, construction and development of urban infrastructure (Oke 1982). Unlike vegetated areas, the urbanised surfaces have higher temperature due to the high capacity of heat absorption and low evapotranspirative cooling effect (Taha 1997). Dense urbanisation generates increased temperature leading to intense energy consumption, higher anthropogenic heat production and more greenhouse gas emissions that also contribute to climate change (Oke 1982). Climate change and its particular consequences for cities including the emergence of global warming and frequent occurrence of heat waves and thus extreme air temperature have been well studied in recent decades (Stehr and Storch 1994, Arnfield 2003, Gill et al. 2007, Booth 2012). Figure 3.1 shows how the complex interrelationships of different elements in the ecosystems of cities yield to thermal discomfort.

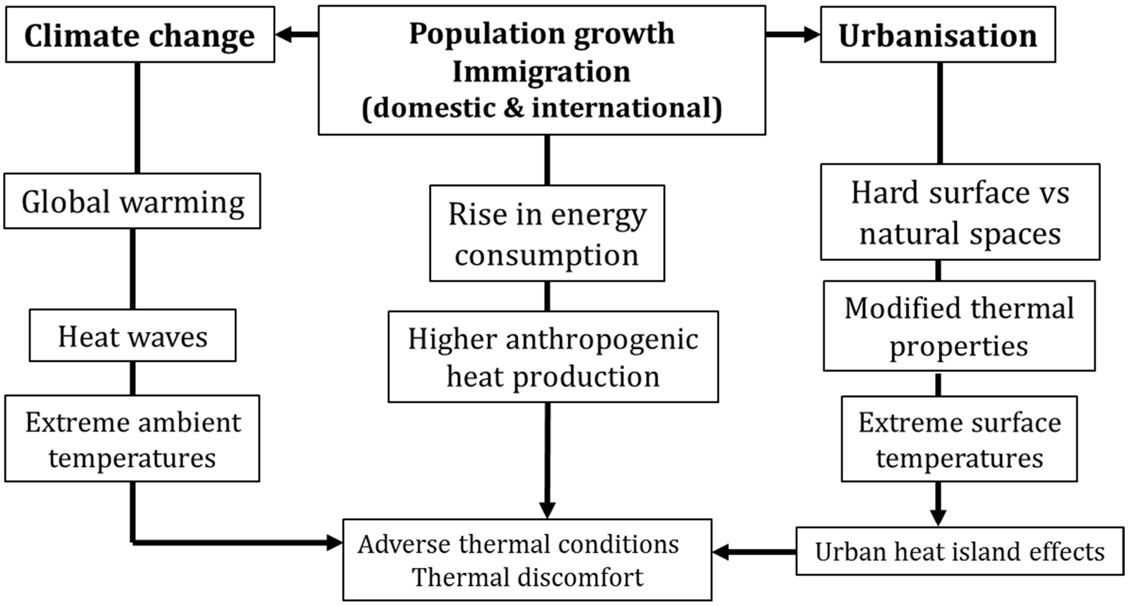


Figure 3.1 Combined effects of climate change and urbanisation on thermal comfort

The importance of the outdoor environment is linked with the provision of spaces for everyday commuting, activities and its influences on urban liveability (Frank et al. 2003). Encouraging the general public to use outdoor spaces is of benefit from several perspectives, including economy, environment, society and individual physical conditions (Zacharias et al. 2004). Among determinants of the quality of outdoor, high priority is given to ambient climatic conditions (Nikolopoulou et al. 2001). People who are exposed to outdoor conditions are directly influenced by microclimatic variables (Nikolopoulou and Lykoudis 2007). The quality of usage of outdoor settings by people, therefore, is highly dependent on climatic conditions. In several studies, it was found that there is a meaningful correlation between the conditions of local microclimate and attendance at events in public places (Nikolopoulou and Steemers 2003, de Montigny et al. 2011, Lin et al. 2013a, Huang et al. 2015). For instance, de Montigny et al. (2011) observed that pedestrians of nine cities had an increased walking rate in association with desirable microclimate conditions. Assessment of environmental parameters, therefore, will assist urban planners to improve the quality of urban life (Frank et al. 2003). As indicated earlier, recent changes in ecosystems of cities have worthened the outdoor thermal environment and compromised human thermal comfort. This is underlined in Australia, where the heat waves were announced to be the third most severe natural disaster by 2012 leading to floods and bushfires (Charleston 2012). Furthermore, Australian capital cities are among the most fast-growing cities in developed countries and there are growing concerns about thermal conditions in these cities (Torok et al. 2001, Lougnann et al. 2010, Block et al. 2012). A summary of the literature review on comfort assessment in Australia is presented in Section 3.6.

3.2.1 ASSESSMENT OF OUTDOOR THERMAL COMFORT: CHALLENGES AND EXAMPLES

As discussed before, the heat balance approach is the main method to calculate the thermal comfort of the given surrounding environment for a large group of people (Fanger 1967, McNall Jr et al. 1967, de Freitas 1985, Mayer and Höppe 1987, Nevins et al. 1966, Parsons 2003, ISO 7730 2006, ASHRAE 55 2010). In this approach, thermal comfort is predicted for a large group of people by solving the given equation of a thermal comfort index using the four meteorological variables and the two personal factors. However, the approach whereby thermal comfort is assessed could be different among comfort research investigations. The following sections document the challenges to assess outdoor thermal comfort including, the need for standardisation of assessing procedures, appropriateness of common thermal comfort indices and the adequacy of current standards in such conditions. It also provides an overview of seminal comfort research projects focusing on the definition of people's comfort conditions in outdoor spaces.

3.2.1.1 Need for standardisation

Retaining the main concepts of outdoor thermal comfort as a backbone of this study, different researchers used a variety of techniques to evaluate outdoor thermal comfort (Johansson et al. 2014). This variation is caused by using different measurement/ calculation methods (Thorsson et al. 2007b, Johansson et al. 2014), thermal indices (Epstein and Moran 2006, Yahia and Johansson 2013), comfort assumptions (Hwang and Lin 2011), thermal comfort modelling approaches (Fiala 1998, Katic et al. 2014, Katavoutas et al. 2015), analytical tests (Parsons 2003, Pantavou et al. 2013), study site conditions (Thorsson et al. 2007a, Chen and Ng 2011, Krüger et al. 2015, Hwang and Lin 2011), availability/limitations in facilities (Patil and Chalfoun 2009, Krüger and Rossi 2011), differences in target population (Eliasson et al. 2007, Aljawabra and Nikolopoulou 2010, Lam et al. 2016), and time of the year (Spagnolo and de Dear 2003, Nikolopoulou and Lykoudis 2006, Lin 2009, Kenawy and Elkadi 2011). The differences among studies' procedures to assess thermal comfort induce discrepancies in expected outcomes arising from the analysis of observed comfort. By way of illustration, a few techniques exist to record solar radiation used to calculate the mean radiant temperature (Thorsson et al. 2007b, Patil and Chalfoun 2009, Krüger et al. 2014). Table 3.1 summarises how different studies adopted various protocols to measure solar radiation. This example along with technical and conceptual differences listed above clearly underlines the necessity for standardising protocols used to evaluate outdoor thermal comfort in the absence of standards.

Table 3.1. Assessing techniques of T_{mrt} in outdoor thermal comfort studies

Measurement method	*References*	*Key findings*
Tg, Ta, Va	Nikolopoulou et al., (2001), Nikolopoulou and Lykoudis(2006), Thorsson et al. (2007), Krüger and Rossi (2011), Linet al. (2011), Bröde et al. (2012), Cheng et al. (2012),Makaremi et al. (2012), Ng and Cheng (2012), Xi et al. (2012),Krüger et al. (2013), Yahia and Johansson (2013), Yang et al.(2013)	Easy to use for outdoor conditions, however, varied sizes and colour codes employed for globe thermometer. Proving the influence of T_{mrt} on thermal perception
Incoming short and long wave radiation from six directions	Oliveira and Andrade (2007), Andrade et al. (2011), Kántor et al. (2012), Krüger et al. (2014)	This is an arduous procedure but yielded an accurate outcome, the measuring approach is insufficient to represent the radiation field in respect to the human body
Incoming short wave (direct, diffuse and reflected) and long wave radiation from two directions	Spagnolo and de Dear (2003), Krüger et al. (2014)	Use of algorithm developed by Jendritzky et al. (2001) to simplify the integral radiation measurement procedure
Incoming global shortwave radiation and Modelling with the RayMan software	Thorsson et al. (2004, 2007), Lin (2009), Lin et al. (2011), Krüger et al. (2014)	A small difference between integral radiation measurement and radiation measurement using globe thermometer, therefore use of globe thermometer is a user friendly and cheap option
T_{mrt} calculated from global radiation and ground surface temperature	Mahmoud (2011)	Proved effect of surface coverage material on the calculated T_{mrt}
No calculation of T_{mrt}	Givoni et al. (2003), Stathopoulos et al. (2004), Eliasson et al. (2007), Metje et al. (2008), Yin et al. (2012)	Using some thermal comfort indices that T_{mrt} is not considered in their heat-balance model

Source: adopted and modified from Johansson et al. (2014).

3.2.1.2 Major projects on outdoor thermal comfort

In outdoor thermal comfort research, a handful of comprehensive research projects exists that define comfort conditions for urban residents, and ascertain people's health and wellbeing (Lin and Matzarakis 2008, Nikolopoulou 2011). Project RUROS (Rediscovering the Urban Realm and Open Spaces) funded by the EU 5th Framework Programme (Nikolopoulou 2011) was conducted in European countries. The objective was to develop comfort models for the study cities. In this project, a wide range of comfort conditions was examined through extensive field surveys with 9270 participants throughout Europe. Included in the study parameters were microclimate variables, urban forms, climatic background, and personal factors representative of different users visiting outdoor settings. The outcomes yielded a series of models (http://alpha.cres.gr/ruros/) characterising comfort conditions for various climate conditions at urban block scale (Nikolopoulou and Lykoudis 2006). Since releasing the results, several thermal comfort studies have been inspired by this project and adopted the techniques used in this seminal work (Oliveira and Andrade 2007, Lin 2009, Andrade et al. 2011, Kántor et al. 2012b).

In Taiwan, Lin and Matzarakis (2008) undertook a comfort research project titled as Impact Evaluation and Strategy on Reciprocal Effects of Tourism and Climate Change, sponsored by the National Science Council of Taiwan to evaluate comfort requirements of tourists visiting a popular vacation destination. The objective was to explore thermal ranges of comfortable and discomfort conditions in the local climate conditions. The researchers employed thermal responses documented in 1644 interviews to determine the tourist comfort conditions in Sun Moon Lake, Taiwan. Accordingly, they developed a plan called "the Climate-Tourism-Information-Scheme" to integrate the assessment of thermal comfort and aesthetic and physical aspects. One criticism of this study is that they correlated the data of interviews in 2005 to climate conditions of a longer period, specifically of 10 years. This correlation overlooks the significance of changes in contextual factors and adaptation that have taken place over one decade.

A university-funded project was launched to evaluate thermal comfort requirements in urban spaces of subtropical and humid Singapore (Yang et al. 2013a, Yang et al. 2014, Yang et al. 2013b). Using information from 2036 participants and a Geographical Information System (GIS) this study generated a diurnal and nocturnal thermal comfort map for 13 different urban spaces in Singapore with the levels of respective thermal comfort. This comprised a comparative analysis with data obtained from another study in China concerning the development of a thermal index that determined comfort requirements in subtropical Asia. This work also emphasised the need to calibrate the thermal comfort indices specific to a particular climate zone by means of pooling the observed comfort data gathered in similar conditions. These data could potentially contribute to developing thermal comfort guidelines or standards for outdoor spaces. In Hong Kong, a research project called the Urban Climate Map (UCMap) was initiated with the goal of producing an urban climate map (Ng and Cheng 2012). The research accounted for urban climatology, urban morphology, and planning practices to produce such maps in Hong Kong's open spaces. This study also used GIS to link urban fabric, land use, and greenery to outdoor thermal comfort. This project was expected to understand and articulate the factors involved in the heat load in Hong Kong's unique urban forms in relation to people's health and wellbeing. The researchers engaged in this project have used the results of user longitudinal and transversal surveys and thermal comfort indices to develop the thermal categories of Hong Kong UCMap (Ng and Cheng 2012). The methodology used in this UCMap project with some changes has been frequently implemented in 15 counties (Ren et al. 2011).

3.3 THERMAL COMFORT AND USE OF OUTDOOR SPACES

Meteorological conditions play a key role in people's presence outdoor. Meteorological conditions govern the load of attendance and the quality of activities performed in an outdoor space. Due to social, environmental, and financial reasons the study of usage pattern has become a central agenda in many comfort studies (Thorsson et al. 2004b, Nikolopoulou and Lykoudis 2007, Aljawabra and Nikolopoulou 2010, de Montigny et al. 2011, Lin et al. 2012, Lin et al. 2013a). However, it has been found that the extent of this influence varies in different contexts depending on cultural (Knez and Thorsson 2006), social (Wilson et al. 2007) and economic differences (Aljawabra and Nikolopoulou 2010, Maras et al. 2014).

Unobtrusive observation is typically used in comfort studies to assess the interaction between climate conditions, people's thermal judgements, and usage patterns and behaviours. This technique is conducted concurrent to measuring environmental variables for further comparisons between thermal conditions and usage patterns. Table 3.2 summarises the characteristics of those studies investigating usage patterns with unobtrusive observation. One typical experimental error associated with field observation is the limited number of observation days, which may not represent the real- world conditions of what is being investigated. This error was previously identified in previous studies such as Lin (2009). Therefore, it is important to choose the days with various thermal conditions that reflect people's interaction with outdoor spaces under various circumstances.

Table 3.2. Characteristics of field observations in outdoor thermal comfort studies

Source	Place- climate	The protocol used	Methodology	Observed activates	Finding(s)
Lin et al. (2013a)	Taichung City (Taiwan)/ Cwa, urban park	30-minute interval during scattered weekends of 4 months.	Observation of activities and total attendance	Seating, reading, sun bathing, picnicking, playing, flying kite/Frisbee, total attendance	Significant correlation between total attendance and thermal conditions
Égerházi and Kántor (2011)	Szeged (Hungary)/Cfb, Urban parks	10-minutes interval over two seasonal periods	Observation of momentary and cumulative attendance	Exposure to sunlight (sun, penumbra, shade), passive activities (standing, sitting, lying), active activities (playing, walking around)	Dependence of attendance on thermal conditions
Aljawabra and Nikolopoulou (2010)	Marrakech (Morocco) /BSh, park, plaza Phoenix (US)/ *Bwh,* park beach lake, market place	20-minute interval in three periods (morning, noon and late afternoon)	Observation of activities and the total attendance	Meeting, watching, chatting, fishing, eating, reading, walking the dogs,	High correlation between attendance and weather conditions
Lin (2009)	Taichung City (Taiwan)/ Cwa, public square	10-minute interval (16:00 to 17:00 pm)	Observation of activities and total attendance	Total attendance	High correlation between attendance and weather conditions
Nikolopoulou and Lykoudis (2007)	Athens & Thessaloniki (Greece)/Cfa Milan (Italy)/Cfa, Fribourg (Germany)/Dfb, Cambridge & Sheffield (UK)/Cfb, Kassel (Cfb), urban square and waterfront	Throughout day, over three seasons	Record of total attendance	Not available	High correlation between attendance and weather conditions
Thorsson et al. (2007a)	Matsudo (Japan) /Cfa, urban park, urban square	20-minutes interval according to a predefined schedule	Unobtrusive observation of the naturally occurring behaviours	Sitting and standing in sun, eating and drinking, reading, playing and exercising, talking on mobile phone, smoking, walking through and total attendance	Attendance in urban square and park is independent and dependent of thermal conditions, respectively
Eliasson et al. (2007)	Göteborg (Sweden) /Cfb ,urban square, courtyard, park and watewrfront	20-minute interval during (11:00 am to 3 pm)	Unobtrusive observation of the naturally occurring behaviour	Lying, sitting, walking, eating, taking, reading	Dependency of usage pattern on thermal conditions
Zacharias et al. (2004)	San Francisco (US) /Csb, urban plazas	30-minute interval, (11:30 am to 3 pm)	Record of total attendance and type of behaviour	Exposure sunlight (sun, shade), standing, sitting, smoking	Relationship between microclimate and usage behaviour

As tabulated above, there are variations in protocols used to establish the association between thermal conditions and usage patterns. However, the main measure is the "total attendance" against the thermal conditions. Type of activity also attributed to climate conditions (Lin et al. 2013b); it means that with change in weather conditions the quality of outdoor activities will also change. The other source of information regarding usage pattern and behaviour is field survey. In addition to these parameters, purpose of visit and place character can also determine usage pattern irrespective of existing thermal conditions. In this regard, some studies have proved the independence of usage pattern on thermal conditions (Thorsson et al. 2007a, Zeng and Dong 2015), where use of certain public places was found to be less correlated to thermal conditions. Therefore, answers to questions on reason and frequency of visit, the time spent outdoors provide valuable information about the dynamics of spatial usage under particular thermal conditions (Eliasson et al. 2007).

3.4 ASSESSMENT OF OUTDOOR THERMAL COMFORT AND CONTEXTUAL FACTORS

Since the development of the adaptive comfort model, attention has shifted to contextual factors that can explain the variations in peoples' thermal perceptions (de Dear et al. 1997, Nikolopoulou et al. 2001, Nicol et al. 2012). According to the adaptive hypothesis, contextual factors and past thermal history influence thermal expectations and thus thermal perceptions (Brager and de Dear 1998). Modified expectations through mechanisms, involved in thermal adaptation, lead to thermal satisfaction with the immediate thermal environment. Furthermore, as cognitive processes are directly interconnected to thermal perceptions, they are subject to change due to variations in the emotional state (Blaney 1986, Kuiken 1991), and each psychologically/socially-effective factor, including contextual parameters, which is potentially able to change thermal perceptions. The notion hinges on the fact that humans are active thermal recipients rather than passive agents (de Dear et al. 1997). On one hand, this active agent can influence ones' perception of comfort by changes in behaviour, immediate environment, or social norms (Shove 2003). On the other hand, this active recipient is believed to be influenced by contextual factors. These factors have been the subject of many studies, mostly indoor thermal comfort (Halawa and van Hoof 2012). However, interest has grown among comfort scholars in exploring how and to what extent contextual factors can mediate thermal perceptions. This section is the critical analysis of literature pertaining to contextual factors in outdoor thermal comfort studies. Due to the varying nature of these factors, they are classified under five categories: individual, social, physical, psychological, and policy and standards. Table 3.3 presents the studies investigating the role of various contextual factors in forming people's thermal perceptions outdoors.

Table 3.3. Summary of studies investigating contextual factors in outdoor spaces

Geographical zone/climate	Individual				Social			Physical				Psychological					No. votes	Study site	Source
	Age & gender	Clothing insulation & activity level	Skin colour	Body posture	companionship	position	Cultural background	Design descriptors	Thermal history	Length of residence	Time of exposure	Purpose of visit	Frequency of visit	Naturalness, spatial feature & place	Seasonal change	Overall comfort & thermal preference			
Temp/ BWh	✓	✓					✓		✓			✓			✓	✓	1284	University campus	Middel et al. (2016)
Belo Horizonte/ Aw	✓	✓	✓														1693	Squares	Hirashima et al. (2016b)
Aachen/*Cfb*	✓				✓	✓											2180	Square, urban area	Maras et al. (2014)
Melbourne/ *Cfa*	✓	✓					✓			✓	✓						1021	Square	Kenawy and Elkadi (2013)
Athens /Csa	✓	✓			✓		✓		✓		✓	✓	✓		✓	✓	1706	Coast side	Pantavou et al. (2013)
Nanjing/ Cfa	✓	✓							✓				✓				205	University campus	Yin et al. (2012)
Curitiba/Cfb	✓	✓							✓	✓	✓				✓		1654	Urban spaces	Krüger and Rossi (2011)
Marrakech/ Bsh Phoenix/ Bwh	✓					✓	✓		✓								303 126	Lake, park, plaza, waterfront	Aljawabra and Nikolopoulou (2010)
Taichung City/ Cwa	✓	✓										✓			✓	✓	505	Square	Lin (2009)
Lisbon /*Csa*	✓	✓	✓														91	Riverside	Oliveira and Andrade (2007)
Goteborg/ Cfb Mastsudo/Cfa	✓						✓							✓			106	Public square	Knez and Thorsson (2006)
Athens, Thessaloniki Milan, Fribourg, Cambridge, Sheffield Kassel (Cfb)																	10,000	Public spaces	Nikolopoulou and Lykoudis (2006)
Dhaka/Aw	✓	✓				✓		✓	✓		✓						1500	Urban spaces	Ahmed (2003)

3.4.1 THE ROLE OF INDIVIDUAL FACTORS IN THERMAL PERCEPTIONS

Gender, age group, the level of metabolic activity, and clothing insulation are the individual parameters most examined in thermal comfort studies (Thorsson et al. 2007a). However, it is vital to investigate other less-considered factors, including users' physical attributes, behaviour, and socio-cultural characteristics particularly in outdoor thermal conditions (Brager and de Dear 1998, Knez et al. 2009). The moderating effects of the individual parameters on thermal sensations are discussed below:

Many laboratory-based experiments have been conducted to understand the individual physical attributes' interaction with given thermal conditions (Fanger 1970, Gagge et al. 1986, Parsons 2002, Arens and Zhang 2006). The dominating role of skin was identified in the body's thermoregulation which takes place through heat transfer from the skin's surface (Gagge and Gonzalez 1974). Despite the evidence for the relationship between skin colour and thermoregulation (Arens and Zhang 2006) through the varying absorptivity of solar radiation of different skin colours (Hoppe 1992, Lyons et al. 2000), there is no convincing explanation of how skin colour may influence human thermal perceptions (Zhou et al. 2014). Previous outdoor thermal comfort studies including a study by Oliveira and Andrade (2007) did not find skin colour to impact on thermal perceptions.

The human body's posture largely influences the heat exchange between it and the given thermal environment (Parsons 2003) and may also take the form of behavioural adaptation to meteorological conditions (Oliveira and Andrade 2007). Kurazumi et al. (2008) conducted an experiment on the effect of the body's posture on heat exchange in nine positions. They concluded that this factor has a noticeable effect on heat transfer areas of the human body when it is near to steady state conditions. There is no consistency in the findings about the role of gender in determination of thermal perceptions (Tung et al. 2014). While some have reported insignificant or no effects (Knez and Thorsson 2006, Krüger and Rossi 2011), others have indicated its moderating effect on thermal perceptions (Oliveira and Andrade 2007, Nasir et al. 2012, Pantavou et al. 2013, Tung et al. 2014, Lam et al. 2016). A comprehensive meta-analysis on gender's role in indoor thermal comfort (Karjalainen 2012) identified differences in the preferences of females and males. The effect of age on thermal perceptions in several studies, likewise, has shown contradictory results; while some have failed to prove its significant effect (Knez and Thorsson 2006, Nasir et al. 2012) others have endorsed its effective role in the moderation of thermal sensation (Knez et al. 2009, Farage 2010, Krüger and Rossi 2011, Pantavou et al. 2013).

The level of exposure to solar radiation is also considered a determinant of thermal perceptions. The significant effect of the exposure to sun on outdoor thermal comfort has been reported (Pantavou et al. 2013, Watanabe et al. 2014, Lin et al. 2010). The human body's posture largely influences the heat exchange between the body and surrounding thermal environment (Tikuisis and Ducharme 1996, Parsons 2003) and may also take a form of behavioural adaptation to meteorological conditions (Oliveira and Andrade 2007). Kurazumi et al. (2008) conducted an experiment on the effect of body posture on steady state heat exchange and concluded that this factor has a noticeable effect on the heat transfer of the human body.

3.4.2 THE ROLE OF SOCIAL FACTORS IN THERMAL PERCEPTIONS

Compared to physiological (Fanger 1970, Gagge et al. 1986, de Dear et al. 1989), psychological (Nikolopoulou and Steemers 2003, Brager and de Dear 1998, Knez and Thorsson 2008) and the place character (Eliasson et al. 2007, Djenane et al. 2008, Krüger et al. 2011) aspects of thermal comfort, less attention has been given to the impacts of social factors. Halawa and van Hoof (2012) argued that cultural and social factors were not a substantial part of key studies assessing thermal comfort. O'Brien and Gunay (2014) linked the disregard of such factors with the misinterpretation of their significance, the difficulty of their quantification and high cost of observational studies. One of the first attempts to include these factors in the assessment of thermal comfort was the publication of a special issue of Energy and Buildings (Kempton and Lutzenhiser 1992). This issue was designated to the cultural and social dimensions of building occupants.

Socioeconomic factors may influence people's thermal perceptions (Aljawabra and Nikolopoulou 2010). This category, incorporates a wide range of factors that can potentially affect people's thermal perceptions; therefore, only a few of these are reviewed. Individuals from a rigid social-background with certain restraints in their life style may place more restrictions on the available thermal adaptive options compared to others with a more flexible lifestyle (Humphreys and Nicol 1998). The potential relationship between socioeconomic background and thermal comfort requirements has been the focus of a few indoor and outdoor analyses (Aljawabra and Nikolopoulou 2010, Indraganti and Rao 2010, Maras et al. 2014). For instance, while Aljawabra and Nikolopoulou (2010) contended that those with a better economic/education status were more sensitive to prevailing outdoor climate conditions, Maras et al. (2014) indicated that generally a better economic status reduced thermal discomfort.

Climate is another factor that has recently received a lot of attention. Several studies have tried to explore the relationship between cultural influences and thermal perceptions in outdoor environments (Knez and Thorsson 2006, Aljawabra and Nikolopoulou 2010, Kenawy and Elkadi 2013). Climatic background not only reflects ethnic differences in perceptions of thermal environments (Fukazawa and Havenith 2012), but also the role of cultural norms in adaptation to prevailing thermal conditions (Humphreys and Nicol 1998). For instance, in some countries, according to the local cultural values, people tend not to modify their clothing largely in response to thermal conditions. This, therefore, limits the thermal adaptation options, which have a significant effect on thermal sensation (Aljawabra and Nikolopoulou 2010). Furthermore, considering the psychological adaptation mechanism (Nikolopoulou et al. 2001) it could act as a deterrent in people's perceived control and induces thermal discomfort.

Culture is a system that defines how people in a group, society, or nation follow the same standards/norms/attitudes for evaluating, believing, understanding, interpreting and behaving (Eisler et al. 2003). Knez and Thorsson (2006) stated that *"…perceptual assessments of a physical place may be intertwined with psychological and cultural processes, rather than fixed by general thermal indices developed in line with the physiological heat balance models"* (2006 p. 258). Culture is closely tied to social norms, level of access to knowledge and technology, religion and traditional beliefs (Kuiken 1991). In Australia, Kenawy and Elkadi (2013) found that thermal perceptions differed among the culturally diverse users of urban open spaces and Lam et al. (2016) reported that Chinese tourists' thermal perceptions and preferences differed from that of Australian residents.

Cultural aspects of comfort also have a bearing on human psychological-related attributes including intelligence, categorisation, self-perception and cognitive processes (Knez and Thorsson 2006). It has been proven that culture affects the assessment of human ecology (Eisler et al. 2003), and the social construct of climate-based issues (Stehr and Storch 1994). Knez and Thorsson (2008) indicated that people with environmental-oriented attitudes tolerate better the thermal environment. Aljawabra and Nikolopoulou (2010) observed that those who consider themselves as outdoor persons could better adapt to thermal conditions and stayed longer in the open-air. The effect of environmental attitude (personal attitude toward open environment) on thermal comfort in the form of naturalness (a component of psychological thermal adaptation) is already highlighted in comfort literature (Nikolopoulou and Steemers 2003, Thorsson et al. 2007a, Kántor et al. 2012a). Knez and Thorsson (2008) argued that generally cultural and social factors that affect behaviour, belief and perceptions are types of schemata. Schemata are series of knowledge structures and expectations preserved in long-term memory, which can elicit behavioural, affective and cognitive consequences (Minsky 1974).

Differing climate/geographical zones are also classified as different cultures (Knez and Thorsson 2006). However, Kenawy and Elkadi (2013) separated the cultural and climatic background as two differing factors in the assessment of outdoor thermal comfort. The results showed a larger effect for climatic background than climatic background. Knez and Thorsson (2008) observed varying thermal perceptions between the Swedish and the Japanese despite relatively similar thermal conditions. The discrepancies were then attributed to cultural differences. They found that the Swedes felt happier and perceived thermal conditions to be more pleasant than their Japanese counterparts did. The authors inferred that a cultural difference was the cause; they proposed that individualism in Sweden outweighed the collectivist culture in Japan regarding tolerance of adverse weather conditions. Even in a study in Taiwan, the low tolerance of females to environmental parameters and sun exposure in particular was related to a cultural desire to have a lighter skin tone (Tung et al. 2014). Authors argued that women have developed an environmental attitude reflected by avoiding exposure to direct sunlight in favour of pale skin colour. This is a social learning process taught through observation, learning, and imitation. Results of a comparative study amid people form three distinct climate zones (Cohen et al. 2013) and another study with two relatively similar zones (Aljawabra and Nikolopoulou 2010) showed different acceptable thermal ranges. They suggest there is a relationship between adaptation, thermal perceptions, and culture (climate). Figure 3.2 illustrates the modifying effect of culture on the relationship between physical environment (place) and thermal perceptions (human responses).

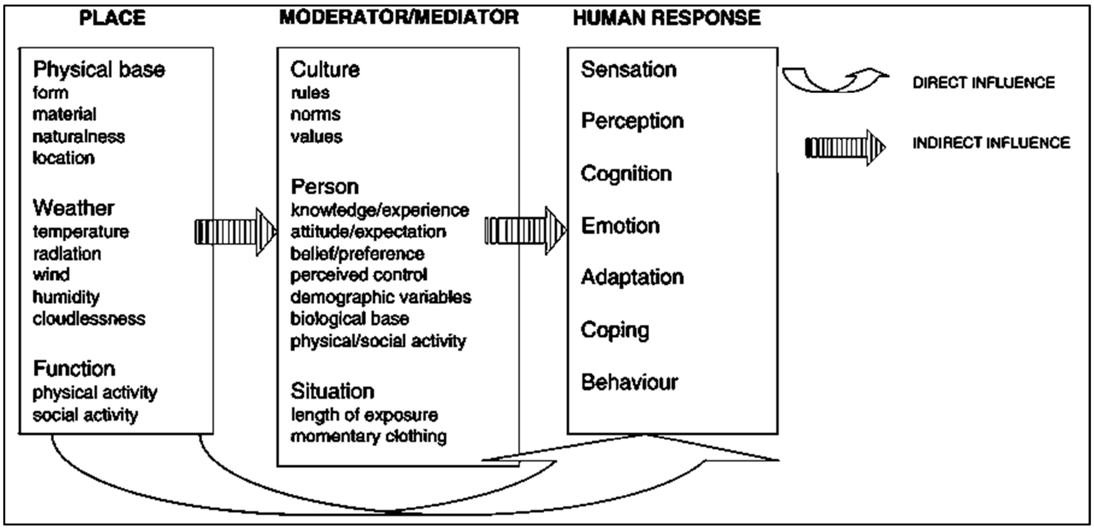


Figure 3.2. Schematic influence of an outdoor space on human thermal perceptions through moderators
Source: Adapted from Knez et al. (2009).

Companionship is a social environment factor that can modify thermal sensation. Being unaccompanied was found to be a cause of thermal discomfort in outdoor environments near the Mediterranean (Pantavou et al. 2013, Oliveira and Andrade 2007) and temperate climates (Maras et al. 2014). Klinenberg (2015) stated that the lack of social embeddedness, including having an isolated life style could lead to a higher death rate during heat waves. People's position in society is shaped by their educational or economic background or their jobs. Since all these elements may influence thermal perceptions, the social position of people is recognised as a contributing factor in thermal perceptions of outdoor environments. Education is a determinant that is directly engaged with culture and norms. In a study thermal requirements of well-educated occupants were found to be higher than those of others (Yamtraipat et al. 2005). Frontczak and Wargocki (2011) in an attempt to find determinants of indoor thermal comfort concluded that level of education influences thermal perceptions. It seems that education's influence is due to its modifying effect on a recipient's thermal preferences and expectations. Having knowledge of climate conditions and its impact on health conditions has allowed well-educated people to achieve thermal comfort at higher levels. Some other thermal comfort studies also considered educational level of participants (Erlandson et al. 2003, Wang et al. 2010, Taib et al. 2010) but no correlation was established to explain the possible relationships.

One concern with the investigation of social factors is how to classify them in relation to the assessment of thermal comfort. This can be a source of misperception as different persons may interpret social factors in dissimilar ways. There is also a probability of confusion among the factors if the boundaries are not clear or overlaps are not recognised. A good example of this is evident in one study (Zacharias et al. 2001) where the spatial behaviour of smoking and people's presence in sunny spots was categorised as a social factor; or in another study gender and age were regarded as social characteristics of participants (Chen and Ng 2012). It seems that the definition of socially- driven influential factors has a degree of flexibility-for different climate/cultural zones. Along with a standardisation of the protocols they can reduce the perplexities and increase the validity of the thermal comfort assessment.

Economic status can change the quality of thermal judgement (Brager and de Dear 1998) and modify it in several ways. Economic factors leave their effects on the level of activity (Frank et al. 2003), outdoor usage pattern (Wilson et al. 2007) and taking particular adaptation strategy (Fuller and Bulkeley 2013). Economic factors, which can potentially impact on thermal perceptions include individuals' economic background, state of health, type of employment, and available technology. In general, people from a poor economic background are expected to have less than ideal health conditions and subsequently, are more vulnerable to outdoor thermal conditions (Maras et al. 2014). Maras et al. (2014) observed that those who are wealthier could better cope with outdoor weather conditions because of more available comfort winner alternatives, including travel to cool green areas, receiving quality healthcare, and residing in air-conditioned homes. Conversely, a better financial situation in other studies was found to be a deterrent to thermal comfort achievement. This tendency may arise from the self-protection perspective, suggesting that well-off people have higher expectations and are comparatively less satisfied with any weather conditions. An indoor study in India also confirmed that people belonging to higher economic groups expressed higher thermal dissatisfaction (Indraganti and Rao 2010).

Employment or job conditions as an indicator of economic status may also affect thermal perceptions, however, little has been written about the relationship between outdoor thermal perceptions and type of job. The relationship between job satisfaction and thermal perception has been well studied in indoor comfort research (Frontczak and Wargocki 2011). Furthermore, it is proven that the conditions of thermal environment have an impact on job satisfaction (Paciuk 1989), safe working behaviour (Ramsey et al. 1983) and performance (Wagner et al. 2007). In Australia, Cena (1999) observed an increasing trend in job dissatisfaction with the rise in thermal dissatisfaction among building occupants. Sharmin and Rahaman (2012) maintained that outdoor thermal perceptions differed between employers with outdoor or indoor jobs.

Economic state of societies changes the condition of thermal comfort when the urban quality of life rises. It is hypothesised that thermal satisfaction is dependent on the societies' general wealth (Wilson et al. 2007). Efforts have been made to compare comfort requirements of different societies including Japan and Sweden (Knez and Thorsson 2008), Americans and Moroccans (Aljawabra and Nikolopoulou 2010), Taiwanese and Mediterranean people (Cohen et al. 2013), Chinese and Singaporeans (Yang et al. 2013a), Taiwanese and Hungarians (Kántor et al. 2014), Australians and Chinese (Lam et al. 2016), Germans and Brazilians (Hirashima et al. 2016a). Yet with the exception of the study by Aljawabra and Nikolopoulou (2010), no convincing evidence was reported to reject or support this hypothesis.

In a comparative study, more residents in a developing country were found to enjoy the outdoor warmth relative to their counterparts in a developed country (Aljawabra and Nikolopoulou 2010). This was related to poor indoor thermal conditions in the developing country. Here the role of thermal expectations is evident where people from a developed country stepping into an outdoor space with variable weather conditions from a conditioned space are more likely to be thermally stressed. To overcome this issue Wilson et al. (2007) suggested developing well-designed open-spaces where various urban elements provide and facilitate outdoor stays lasting longer.

3.4.3 THE ROLE OF PHYSICAL PARAMETERS IN THERMAL PERCEPTIONS

In general, physical factors including local climate conditions and individuals' physical and physiological conditions have the most significant effect on thermal judgement. Included in this category are design pattern of spaces, length of residence, time of exposure to environmental parameters and type of users.

The role of urban design and characteristics has long been the focus of many scholarly works, such as UHI effects, pavement conditions, and climate change (Oke et al. 1991, Akbari and Taha 1992, Unger 1999, Coutts et al. 2007b, Stewart and Oke 2012). In spite of such a long history, until recently, less attention has been given to the spatial features with regard to assessment of human comfort requirements in outdoor thermal environments (Spagnolo and de Dear 2003). One possible explanation for this shortcoming is related to the smaller number of thermal comfort studies in outdoor settings compared to those indoors. The reasons for this inequality were addressed below (Spagnolo and de Dear 2003):

1. Studies focus more on the developed countries where residents spend most of their lives in indoor settings
2. Since thermal comfort largely affects office-building occupants' workplace performance, it is of great importance to provide them with a preferable thermal environment.
3. Engineering and control over influencing factors on outdoor localities is barely achieved compared to indoor ones.
4. Proprietorship is not typically as clear as that in indoor surroundings.

This trend, however, discontinued as the number of urban residents sharply increased and the inevitable changes in urban design and planning led to climate change having adverse effects on urban microclimates in different climates (Zacharias et al. 2004, Johansson 2006a, Alexandri and Jones 2008, Krüger et al. 2011). In recent time, the role of spatial design in the determination of thermal perceptions has been carefully investigated (Djenane et al. 2008, Lin et al. 2010, Bourbia and Boucheriba 2010, Mahmoud 2011, Qaid and Ossen 2014). The studies tried to disclose the effects of partly unknown design factors in urban bio-climate by either comparing varying urban spaces (Johansson and Emmanuel 2006, Krüger et al. 2011) or using simulation case scenarios (Ali-Toudert and Mayer 2006, Elnabawi et al. 2016).

Two most frequently investigated features of urban design in relation to human thermal comfort are aspect ratio and sky view factor. These two factors are preferred due to ease of calculation and their proven effects on urban microclimate (Oke 1982, Eliasson 1992, Matzarakis et al. 2007, Lin et al. 2010, Bourbia and Boucheriba 2010). As indicated in previous studies, these factors can alter the air movement pattern (wind speed), solar radiation intensity (mean radiant temperature) and thus give variation to shadow pattern (air and surface temperature). Table 3.4 summarises the key findings of studies on the impact of these two design descriptors on outdoor thermal perceptions.

Table 3.4. Summary of studies investigating the thermal conditions in relation to urban design

City	Factor(s)	Findings	Reference
Putrajaya	H/W ratio	Asymmetrical streets provide better thermal comfort via enhancing wind flow and blocking solar radiation. Aspect ratios between 0.8 and 2 ensure noticeable reduction in air and surface temperature in tropical regions.	Qaid and Ossen (2014)
Cairo	SVF, albedo	Due to their shading and sheltering effect against intense solar radiation and wind patterns, tree-planted areas can provide better thermal comfort conditions in urban parks located in arid regions, respectively in summer and winter	Mahmoud (2011)
Huwei Township	SVF	Highly shaded outdoor spaces, featuring lower SVF values, are more beneficial in hot and humid climates in summer, spring, and autumn.	Hwang et al. (2011)
Curitiba	SVF, street orientation, wind flow	While the similar comfort conditions were observed on days with low temperature in all study locations, on hot days, areas with lower SVF provided better thermal comfort	Krüger et al. (2011)
Huwei Township	SVF	Barely shaded areas (high SVF percentages) had longer hours of discomfort in summer and more; whereas densely shaded-areas were more dis-comfortable in wintertime.	Lin et al. (2010)
Constantine City	SVF, H/W, street orientation	With some few exceptions SVF and H/W ratio values had respectively positive and negative correlation with air and surface temperature	Bourbia and Boucheriba (2010)
Beni Isguen city	SVF, H/W ratio, plot ratio	The dependency of thermal behaviour on both solar exposure and magnitudes of wind velocity	Djenane et al. (2008)
Fez	H/W ratio, SVF	Spaces with higher percentages of SVF had comparatively higher nocturnal air temperature due to release of heat stored by surfaces during the day caused by incoming solar radiations.	Johansson (2006a)

Aspect ratio is the ratio between the average height of buildings and intermediate width of the given street. This feature influences the magnitude of both incoming and outgoing solar radiation, and wind pattern. Johansson (2006a) argued that aspect ratio improves the level of summertime comfort whereas it is a source of discomfort in winter. He also found more stable thermal conditions in deep street canyons with higher aspect ratio compared to shallow street canyons. Djenane et al. (2008) demonstrated the dependence of the given thermal budget on urban design, including H/W ratio. Furthermore, adjustment in H/W ratio was identified as a mitigation strategy in response to hot conditions (Bourbia and Boucheriba 2010).

Solar radiation, including short and long-wave fluxes received by outdoor users influences their energy balance. Sky view factor (SVF) is used to present the level of shading in the open spaces encompassing buildings, trees, landscape and other urban structures which modify the visible horizon and incoming radiation (Oke 1982). SVF is defined as the fraction of free sky at the given location ranging from 0 to 1, indicating completely obstructed and completely vertically free space, respectively (Oke 1982). As SVF controls the diffusion of direct solar radiation, its small values can show a positive and negative impact in summer and winter, respectively, with reference to human thermal perceptions (Eliasson 1994). He et al. (2015) explained further consequences of SVF impact as follows: "*…SVF being an indicator of urban canyon geometry affects the surface energy balance, local air circulation, and outdoor thermal comfort*" (p. 285). In another study, the thermal conditions of eight urban environments in the semi-arid climate of Algeria were investigated; and the built-up surfaces such as asphalt were noted as heat traps needing to be mitigated by the creation of obstacles so as to reduce the SVF level and thus surface and air temperature (Bourbia and Boucheriba 2010). In the hot and arid climate of Cairo, Mahmoud (2011) observed the significant impact of SVF on thermal conditions in eight sub-areas of an urban park. It is worth noting that in some climate conditions while SVF brings thermal comfort, in others it can do the opposite.

Lin et al. (2010) conducted an investigation to understand the long-term effect of SVF on thermal comfort in a university campus in Taiwan. The results showed that the number of discomfort hours varied with the level of SVF, mostly comfortable in a shaded area in the summer and uncomfortable in winter. What was an interesting finding were similar discomfort hours in both seasons, indicating the role of obstacles in controlling the solar radiation and wind speed. However, these findings would have had more meaning if the researchers had considered concurrent thermal responses. In Curitiba, Brazil, one study considered using data from different sources: field measurement, survey and simulation to better characterize the urban design impact on outdoor thermal conditions and comfort (Krüger et al. 2011). Interestingly, the results pointed out that SVF is not crucial in determining thermal comfort and other factors should be taken into consideration. To sum up, the major trend found in the literature shows the impact of urban design on both thermal conditions and perceptions. However, the level of impact on people needs to be investigated in relation to prevailing microclimate, dominant usage pattern, type of users, and function and design of space.

During the last decade, several studies discussed the role of urban elements on the surrounding thermal environment with respect to human thermal comfort, including vegetation (Alexandri and Jones 2008, Shashua-Bar et al. 2011, Peng and Jim 2013), ground and vertical surfaces (Mahmoud 2011), water bodies (Xi et al. 2012, Mahdavinejad et al. 2013) and shading devices (Shashua-Bar et al. 2011). These elements have become an integral part of effective designs for modern urban spaces that also contribute to spatial heat budget. They provide opportunities for space users to implement adaptive strategies to attain comfort in outdoor thermal environments. The interactions between urban vegetation, water features, use of technologies, wind shelters, shade devices, and surface permeability with the urban heat budget are discussed in more detail below.

Green infrastructures produce numerous ecological, social and economic benefits in cities (Gill et al. 2007). Their influence on microclimatic parameters is of paramount importance and mainly identified in modification of RH (Harazono et al. 1990), T_a and T_S (Wong et al. 2003), V_a (Saiz et al. 2006), carbon concentration in atmosphere (Getter et al. 2009) and S_r (Niachou et al. 2001). Affecting the above mentioned variables, green spaces will contribute to resolving a number of issues in cities including: climate change (Gill et al. 2007), UHI effects and heat waves (Oliveira et al. 2011), and thus improve people's wellbeing and comfort (Tzoulas et al. 2007, Klemm et al. 2015a, Shashua-Bar et al. 2011).

The effect of green spaces on outdoor thermal environment originates in four mechanisms: evapotranspiration, shading, photosynthesis and trapping long wave radiation (Kleerekoper et al. 2012). Most studies assessing thermal behaviour of green spaces (Shashua-Bar et al. 2011) observed cooler environments within vegetated spaces

(Niachou et al. 2001, Wong et al. 2003). On average, trees in parks and streets are able to reduce T_a by up to 3 to 4°C, whereas this is recorded by up to 2°C in vegetated areas such as lawns, green walls and roofs (Shashua-Bar et al. 2011). However, temperature reduction is a function of vegetation layer (Wong et al. 2003), season (Sailor 2008), characteristics of urban settings and surrounding buildings (Ali-Toudert 2005), presence of water in growing medium (Simmons et al. 2008, Coutts et al. 2012) and climatic conditions (Alexandri and Jones 2008, Chow et al. 2016). Plant-shaded surfaces receive less direct, diffused, reflected, and short-wave radiations (Wong et al. 2003, Xi et al. 2012). This causes a reduction in T_s and consequently, T_a. Studies on green spaces have reported T_a reduction was as much as 0.4°C in humid continental climates (Rosenzweig et al. 2006) and 4°C in tropical climates (Wong et al. 2003).

While shading and trapping long wave radiation indirectly moderates outdoor thermal conditions, evapotranspiration and photosynthesis directly impact on ambient temperature (Shashua-Bar et al. 2011). Plants' evapotranspiration process along with evaporation from substrate requires energy, which is supplied by the consumption of latent heat and leads to evaporative cooling effects. Photosynthesis contributes to T_a reduction by taking excessive CO_2 (Getter and Rowe 2006) from the atmosphere. This CO_2 accounts for over 60% of greenhouse gas emissions and contributes to increased temperature in the lower atmosphere (Dinsdale et al. 2006).

Water features have been employed in architectural design to create a thermally comfortable environment for a long time (Folk 1974). These days water bodies are often incorporated into urban environments for many reasons such as aesthetic, functional and bioclimatic functions (Shashua-Bar et al. 2011). Water is considered to be instrumental in evaporative cooling especially in hot climates (Mahmoud 2011) and might be used as a design strategy for a comfort environment (Mahdavinejad et al. 2013). Wetted surfaces due to higher evaporation rate and large capacity to absorb surrounding heat can be a source of thermal amelioration in outdoor environments (Coutts et al. 2012). Evidence for this thermal performance can be clearly seen in a Japanese park (Nishimura et al. 1998) where a 3 degrees centigrade reduction in T_a was reported when new water facilities were established in urban spaces. Similar results were found in China, where two thermal indices showed improved thermal comfort within 10 to 20 m of the water bodies (Xu et al. 2010). Xu et al. (2010) stated that the water surface and a 100 m air column above the water commonly influence the process of heat loss through water evaporation. The most widely used forms of water features in cities include fountains, cascades, water channels, and ponds.

In Australia use of water to modify the thermal condition is recommended under a plan developed for the promotion of sustainability titled as Water Sensitive Urban Design (WSUD) (Maritz 1990). Coutts et al. (2012) indicated that "…*WSUD is a novel approach for helping restore natural water balance regimes that are able to support healthy urban vegetation, and purposefully modify the urban energy balance to support CSUD through enhanced evapotranspiration…*". The authors listed the mechanisms through which water bodies can help mitigate adverse weather conditions:

1. Formation of oasis effects by means of increased evapotranspiration
2. Supplying water to support healthy green spaces so that they continue serving as a cooling agent by shade and evapotranspiration
3. Contributing to the reduction in surface radiative temperature.

The use of wind shelters and shade devices for reduction in thermal discomfort has been long practiced. However, only a few studies investigated the actual performance of these devices to improve outdoor thermal conditions (Leech 1985, Watanabe et al. 2014, Shashua-Bar et al. 2011). In hot-arid climate Shashua-Bar et al. (2011) reported that when the shading was cast over pavements the duration of thermal discomfort was reduced by 50%. In Nagoya, Japan, it was found that on sunny days, building and pergola shades were able to reduce Universal Effective Temperature (ETU) by 18.4 °C and 16.2 °C, respectively (Watanabe et al. 2014). Leech (1985) discovered that in an open space the use of windscreens that could modify wind velocity by 60% caused 30% more thermal comfort compared to an open space exposed to wind blasts.

Because of urbanization, the green spaces turned to hard (built) surfaces with higher T_s, leading to more thermal discomfort (Pomerantz et al. 2000, Asaeda and Ca 2000, Akbari and Rosel 2008, Shashua-Bar et al. 2011, Erell et al. 2014). Simply stated, in the canopy layer when the ground surface is hotter than the adjacent air, the heat flow is directed upward, resulted in higher T_a (Erell et al. 2014). The direct link between T_a and T_s can be substantially influenced by intense solar radiation, evapotranspiration and strong winds (Akbari and Rosel 2008).

Some passive design strategies promote modification of ground surface to enhance human thermal comfort (Akbari and Taha 1992, Starke et al. 2010, Coutts et al. 2012). Doulos et al. (2004) investigated the thermal performance of 93 commonly used pavement materials and classified them into “cool” and “warm” materials. The results inform the decisions on selecting appropriate surface materials for urban spaces, which are more climate-sensitive and will improve human thermal comfort. Another good example was a study conducted on the role of permeability of ground surfaces in Germany (Starke et al. 2010). Authors found that permeable pavements (porous) were able to hold 3.8 $L.m^{-2}$ more water than others and hence their evaporative rates were 16% higher. In another study in Japan four surface materials - (i.e. porous block pavement, dark non-porous asphalt, natural grass and ceramic porous pavement) - were tested to evaluate their influence on microclimate during a hot summer (Asaeda and Ca 2000). At noon, the T_s of ceramic porous was similar to that of natural grass, while the porous block was equally hot over asphalt due to low capacity of retaining water. Overall, the materials with more permeability should be applied in densely urbanised areas due to higher water infiltration. Doing so will promote evaporation and lead to better thermal comfort.

Improvement in life quality standards worldwide and technological advances encourages people to employ technologies for mitigating adverse thermal conditions. These technologies are primarily devised to modify the environmental parameters surrounding human thermal environment. However, there are some doubts in the thermal comfort research community about the applicability of such technologies. There is evidence for both the success and failure of using technologies to improve outdoor thermal comfort (Farnham et al. 2015, Chan et al. 2016). This failure is mainly owing to their high costs (most technologies used much energy), low efficiency, and restriction in availability of manufacturing materials. Several studies evaluated the performance of these technologies to judge their capacities to effectively create thermally comfortable conditions outdoors.

Experimenting with the functionality of evaporative spray cooling systems on hot days, Farnham et al. (2015) found that these systems can reduce heat stress for local pedestrians in Osaka, Japan. In 2013, Chan et al. (2016) tested the usability of personal cooling vests in Hong Kong. This technology, first introduced by the Labour Department of Hong Kong (HKSAR 2013) under the "Cooling Vest Promotion Pilot Scheme", aimed to improve thermal comfort of labourers working outdoors in four industries However, this innovation was not successful as expected in trying to achieve the pre-set goals due to high cost and low efficiency.

Length of residence (LoR) and time of exposure (ToE) to outdoor environmental parameters are linked to long- and short-term physical (physiological) thermal adaptation (Brager and de Dear 1998). According to the concept of thermal adaptation, and acclimatization in particular people are expected to be gradually acclimatized to a local microclimate when they are repeatedly exposed to it (Humphreys 1975, de Dear and Brager 1998). This process is otherwise known as physiological thermal adaptation (de Dear and Brager 1998). Also, extended exposure to outdoor environmental stimuli induces the reflective physiological thermal adaptation but in a shorter time (Humphreys and Nicol 1998, Krüger et al. 2015).

ToE in the assessment of thermal comfort is accentuated due to a number of reasons as follows:

(1) users of open spaces often only stay for a short while and are thus transient users (Höppe and Martinac 1998, Leech et al. 2002); (2) behavioural adjustments by people take place following a considerable time spent outdoor (Ahmed 2003); (3) this factor was also categorized under psychological thermal adaptation by Nikolopoulou and Steemers (2003) in that it changes thermal expectations which in turn affects thermal perceptions. On this theme, Krüger et al. (2015) indicated that "...*stepping from thermal homogeneity to transient outdoor conditions should create immediate responses that would then diminish with time of exposure*" (p. 1). Höppe (2002) found that thermal steady state, being the basis of typical thermal comfort indices, is never reached after several hours or may be reached after 30 minutes in cold and warm conditions, respectively. Thermal comfort under non-steady state conditions primarily deals with rapid microclimate transients and noticeable changes in microclimate conditions, level of activity and clothing insulation within the course of minutes (Katavoutas et al. 2015).

Some studies have shown there is a significant relationship between LoR and thermal perceptions in outdoor spaces of various climate conditions, including tropical (Chow et al. 2016) and sub-tropical (Makaremi et al. 2012, Yin et al. 2012, Chen et al. 2015) and temperate climates (Kenawy and Elkadi 2011). In the sub-tropical climate of Shanghai, Chen et al. (2015) observed that during winter long-term residents were better adapted to given thermal conditions. Several research studies wherein the duration of participants' residence was documented but no results were subsequently presented to establish a relationship between LoR and thermal perception (Oliveira and Andrade 2007, Pantavou et al. 2013).

In other studies the importance of LoR was simply neglected where the participants with short-term residencies were excluded from interviews (Krüger and Rossi 2011). Despite obtaining a more uniform study population, excluding such people from the study would result in having a sample size that does not represent the real-world conditions wherein open spaces are likely to be visited by different people. Another assumption associates the thermal perceptions with the psychological mechanisms (i.e. past thermal experience, perceived control and time of exposure to environmental parameters) (Nikolopoulou and Steemers 2003). That means the impact of the financial situation on the thermal perceptions is applicable through changes in the mechanisms mentioned above (Figure 3.2). For instance, occupants of naturally ventilated buildings (Olesen and Brager 2004) and the building owners (Indraganti and Rao 2010) achieved better thermal comfort due to superior perceived control compared to those of air-conditioned buildings and the tenants, respectively.

3.4.4 THE ROLE OF PSYCHOLOGICAL FACTORS IN THERMAL PERCEPTIONS

The role of psychological aspects of thermal comfort was first highlighted in a seminal work on the psycho-physiological model of thermal perception (Auliciems 1981). Through this model, the author explained the mechanism through which the psychological status of people may influence their thermal expectations and satisfaction. This theme was later suggested to be part of the concept of adaptation in the adaptive comfort model (de Dear et al. 1997). Some years later drawing on literature pertaining to psychological adaptation, Nikolopoulou and Steemers (2003) developed the mechanisms of psychological adaptation in outdoor spaces. These included naturalness, perceived control, environmental stimulation, expectations, time of exposure and thermal history. There are other psychological factors that are found to affect outdoor thermal perceptions, including but not limited to, seasonal change, purpose and frequency of visit, place character, and other indicators of thermal perceptions (i.e. thermal preference and overall comfort).

Thermal history is long known to be a key psychological mechanism in adaptation to indoor thermal conditions (Humphreys 1995) and recently in outdoor thermal conditions (Nikolopoulou and Steemers 2003, Knez et al. 2009) which theoretically influences thermal sensation. Past thermal history is often assumed to modify expectations and preferences for thermal conditions (de Dear et al. 1997). The meaningful relationship between past thermal history and thermal sensation has been verified in several studies (Yin et al. 2012, Aljawabra and Nikolopoulou 2010, Lin et al. 2011). Seasonal change profoundly dictates the way people evaluate outside thermal conditions. To better determine the possible effect of seasonal change on outdoor thermal perceptions, many studies evaluated and compared thermal comfort conditions in various seasons (Spagnolo and de Dear 2003, Lin et al. 2011, Shooshtarian et al. 2015, Huang et al. 2015, Middel et al. 2016, Pantavou et al. 2013). It is often assumed that changes in people's thermal expectations coincide with changes in season. Moreover, the neuropsychological concept of perceptual alliesthesia (Cabanac 1971) allows researchers to explain the dynamic of change in people's thermal perceptions in different seasons (Spagnolo and de Dear 2003).

Purpose and frequency of visit (FoV) to an open space could potentially affect people's thermal perceptions according to conventional wisdom. It is assumed that people are gradually acclimatized to a local microclimate when they are repeatedly exposed to it. Reviewing the relevant literature, Johansson et al. (2014) argued that the purpose of visiting an open space influences thermal perceptions as those users passing through an space to reach another place may not be concerned with weather conditions. This is because they are in a recreational space wherein people may avoid visiting due to poor comfort conditions. Intention and frequency of spatial use is somewhat linked to the function of a space. In other words, the function of a place including available facilities, design options and level of accessibility partially determines intention and frequency of usage in one open space (Zacharias et al. 2004, Knez et al. 2009). Several studies have reported that in public spaces with different functions people's thermal evaluation and thus usage patterns differed (Thorsson et al. 2007a, Nikolopoulou and Lykoudis 2007, Spangenberg et al. 2008, Chen et al. 2015). Not much research has assessed the impact of these two factors on thermal perceptions (Nikolopoulou and Lykoudis 2006, Oliveira and Andrade 2007, Pantavou et al. 2013, Chow et al. 2016), So a direct relationship was rarely established (Pantavou et al. 2013, Lam et al. 2016, Middel et al. 2016). Instead, they tried to link usage pattern to the character of various spaces to show such a relationship using usage pattern indicators. These included, for example number of attendants, as a function of thermal perceptions (Nikolopoulou and Lykoudis 2007, Eliasson et al. 2007, Lai et al. 2014b).

Perceived control is one of the six-fold psychological adaptive mechanisms which is proposed by Nikolopoulou and Steemers (2003). The authors argued that "…*people who have a high degree of control over a source of discomfort, tolerate wide variations, are less annoyed by it, and the negative emotional responses are greatly reduced*" (p. 97). Being recognised as the impact of perceived control over outdoor thermal conditions on peoples' thermal perception, this parameter was investigated in a few outdoor thermal comfort studies (Lin 2009, Huang et al. 2015).

Depending on their spatial features, open spaces can attract people for various reasons. Given the fact that each open space may be convenient to people, users theoretically can compromise their thermal judgement to take advantage of such comfort (Nikolopoulou 2004a, Lenzholzer and van der Wulp 2010, Klemm et al. 2015a). Knez et al. (2009) put forward a model to understand the psychological mechanism of thermal perceptions in which the place's character is regarded as a moderating factor in people's thermal experiences. Spatial features include aesthetic and visual characteristics of space, accessibility, facilities provided in place, type of users, and various opportunities to adapt to thermal conditions that together shape place's character. In their studies conducted in Dutch cities, Klemm et al. (2015a) indicated that a large proportion of the variation in general preferences of thermal comfort could be justified by the environment's spatial characteristics. The character of space is closely related to function of place and sometimes they are interchangeably used (Andrade and Alcoforado 2008).

Among others, spatial naturalness is one of the conveniences that a space can offer to users; this term is a two-fold concept: on one hand, it is concerned with the extent to which a user can be connected to nature and on the other hand, it reflects people's opinion on the level of spatial naturalness in open spaces. Nikolopoulou and Steemers (2003) suggested naturalness is one of the six-fold factors in the psychological thermal adaption process in outdoor spaces. However, the psychological effects of vegetated areas on people's thermal perceptions are yet to be fully explored. Lenzholzer and van der Wulp (2010) and later Klemm et al. (2015a) proclaimed that as green spaces improve people's perceptions of places they also affect their perceived thermal comfort.

Overall comfort and preference for a certain thermal condition (two elements of thermal perceptions) could potentially influence thermal sensation. The conceptual and functional characteristics of these elements were compared in previous studies: in indoor, semi-indoor (Brager et al. 1993, Andamon 2005, Zhang and Zhao 2008) and outdoor conditions (Pantavou et al. 2013, Chen et al. 2015, Shooshtarian and Ridley 2016). According to key findings, some studies proved the influence of such elements on subjective thermal sensation (Cheng et al. 2012, Pantavou et al. 2013, Middel et al. 2016). There is some evidence, however, which presents the opposite trend in certain circumstances such as seasides where people sensed thermal conditions outside specified comfort zones while they still preferred the current conditions identified as discomfort (de Freitas 1985, Höppe and Seidl 1991). Therefore, these two perception elements are theoretically linked to other than thermal factors, including psychological drivers, which depend on conditions influencing thermal sensation or otherwise.

Becoming aware of weather conditions an individual would experience during a day is an effective thermal adaptive behaviour. According to the concept of thermal adaptation, people tend to react to a given thermal environment to better cope with environmental stressors. Many people tend to check forthcoming weather conditions prior to leaving an indoor or semi-indoor environment. Getting to know weather conditions outside, not only makes people mentally prepared to given thermal conditions (Yin et al. 2012, Leviston et al. 2015), but also encourages them to physically adjust their clothing or activity for better adaptation (Höppe 1999, Chun et al. 2008). In a report (Leviston et al. 2015) describing Australian attitudes to climate change it is indicated that if people have knowledge of what they are to perceive outside there is a greater likelihood of better adaptation to weather conditions. In a comparative study on the adaptive behaviour of two nations it emerged that the Japanese were more tolerant of weather conditions than their South Korean counterparts simply because the former tended to check weather forecasts more (Chun et al. 2008). They also observed that Japanese people's clothing choices were primarily influenced by weather forecasts rather than fashion. Höppe (1999) indicated that weather reports should also advise audiences on the kind of clothing they should wear before leaving home to provide better thermal comfort. Yin et al. (2012) argued that outdoor users foresee the type of weather conditions they will face and they change their thermal expectations accordingly, which in turn will affect their thermal perceptions.

3.5 OCCURRENCE OF THERMAL ADAPTATION

Since the development of the adaptive approach and its integration into thermal comfort standards for occupants of naturally ventilated buildings (de Dear and Brager 2002), researchers have examined the role of thermal adaptation in people's thermal judgement. In addition to indoor comfort literature, there are many studies evaluating the occurrence of thermal adaptation in outdoor spaces (Nikolopoulou and Steemers 2003, Walton et al. 2007, Hwang et al. 2010, Lin et al. 2011, Parkinson and de Dear 2015, Wu et al. 2015, Hirashima et al. 2016b). In outdoor thermal comfort research, scholars have expanded comfort boundaries to incorporate and characterise thermal adaptation in outdoor spaces. These models included psychological adaptive mechanisms (Nikolopoulou and Steemers 2003), the concept of alliesthesia (Spagnolo and de Dear 2003), and adaptive clothing model (Fiala et al. 2012).

Most of the results obtained from comfort experiments only provided some general information or evidence showing people's adaptation to local thermal conditions and tried to establish a link with components of the thermal adaptation concept. For instance, the results of a study investigating thermal adaptation showed that people primarily undertook behavioural adaptation in response to thermal discomfort, and if the conditions still persisted, they then adopted psychological strategies (Wu et al. 2015). Popular questions in thermal comfort surveys, indicating psychological thermal adaptation, are the status of "thermal history" and "length of residence" (Johansson et al. 2014). A study by Walton et al. (2007) strongly supports the theory of adaptive comfort in a field survey conducted in two urban parks and one mall in New Zealand. The authors observed that people thermally adapt to local meteorological conditions by modifying their clothing, choosing a suitable spot to stay, limit/extend the time of exposure to outdoor environmental variables

Some studies benchmarked their findings against the psychological adaptation mechanisms (Lin 2009, Hirashima et al. 2016b, Lam et al. 2016) and others investigating determinants of thermal comfort, equated contextual factors to adaptation opportunities (Walton et al. 2007, Wu et al. 2015, Makaremi et al. 2012, Yang et al. 2017, Pantavou et al. 2013). For instance, Makaremi et al. (2012) concluded the occurrence of thermal adaptation by comparing people from diverse climatic backgrounds where locals could tolerate climate conditions better than international students. Several studies merely relied on seasonal differences in people's thermal response including thermal neutrality, sensitivity, and other indicators to prove the occurrence of thermal adaptation (Nikolopoulou and Lykoudis 2006, Lin et al. 2011, Huang et al. 2015, Hirashima et al. 2016b).

Some studies also tried to establish a regression model wherein climate variables and few contextual factors helped predict people's thermal comfort; however, these were only specified to local regions (Yang et al. 2013b, Ruiz and Correa 2014). Ruiz and Correa (2014) employed several multiple linear regression models to develop an adaptive model for outdoor thermal comfort in arid zones. The authors hoped that this new model would solve the issues related to low predictability of typical comfort indices in arid zones. To date these research studies have largely not yielded any empirical, universal and well-grounded outcome whereby assessment of outdoor comfort studies can accommodate the elements of thermal adaptation with practice. Some outdoor thermal comfort experts have also indicated that including adaptive comfort is not easy to do. In this regard, Hirashima et al. (2016b) stated "…*as physiological adaptation to a climate is generally slow it is not critical for thermal comfort studies in urban spaces*"(p. 246).

3.6 ASSESSMENT OF OUTDOOR THERMAL COMFORT IN AUSTRALIA

Australia is a leading country in the development of thermal comfort concept, mostly in interior conditions (Macfarlane 1958, Hindmarsh and Macpherson 1962, Wyndham 1963, Auliciems 1981, de Dear et al. 1989, Parsons 2011, Law 2012, Loughnan et al. 2014, Zhang and de Dear 2015) but few in outdoor settings (de Freitas 1985, Spagnolo and de Dear 2003). However, a growing trend regarding the assessment of thermal comfort in Australian outdoor spaces is following the universal demand for assessment of thermal comfort to inform decisions on creation of climate-sensitive outdoor spaces (Coutts et al. 2007b). Therefore, it is necessary to carry out comfort research according to the contextual conditions. Auliciems and Szokolay (2007) remarked that "…*field investigations, using 'real' people engaged in 'real' tasks in 'real' built environments, rather than laboratory experiments into thermal comfort, have produced seemingly anomalous observations that suggest that people's thermal preference also has a geographic component*" (p. 45). Furthermore, for the reasons relating to the specific context of Australian capital cities the need for assessing thermal comfort is highly emphasized. As indicated in Chapter 2, these cities have undergone rapid urbanisation, population growth, migration (i.e. from rural areas and overseas) and are subject to severe effects of climate change (Block et al. 2012).

In Australia, hot weather is becoming more common and severe (Climate Commission 2011). The 2003-2012 decade remains one of the country's warmest with a temperature anomaly of+0.44 °C and all Australian capital cities recorded warmer-than-average maximum temperature values (BoM 2014a). The latest report by the IPCC (2014) stated that Australia will keep getting hotter and thus more mechanical technology will be needed to achieve thermal comfort indoors. The climatic records of 2012-2013 and 2013-2014 on changes in summer temperature reflected this shift to more hot weather events (BoM 2014a). A recent report from the Australian Bureau of Meteorology (BoM) announced the occurrence of heat wave in January 2014 that has been notable from duration and the average maximum T_a perspectives in Australian and state of Victoria, respectively (BoM 2014b). To examine the current state of comfort research in Australia a number of studies were reviewed and their findings were compared. This review covers literature three decades old, from the early work of de Freitas in 1985 to Lam et al. (2016). Table 3.5 summarises the key findings of comfort studies in Australian urban spaces. Further details of each study are subsequently provided.

Table.3.5. The characteristics summary of outdoor thermal comfort studies in the context of Australia

City/climate	Season/ place	Method(s) used	Focus of the study	Reference	Summary of findings
Caloundra/ Csb	All year round beach	Questionnaire, Measurement	Test the applicability of heat balance models under coastal conditions	de Freitas (1985)	Discrepancy between participants' behaviour and their thermal sensation during warm weather conditions alongside beaches. The findings elucidated the difference between thermal preference and sensation regarding thermal satisfaction.
Sydney/Cfa	Winter, summer, semi-outdoor and outdoor spaces	Questionnaire, Measurement	Evaluation of thermal comfort conditions in urban spaces by specifying seasonal neutral and preferred temperature	Spagnolo and de Dear (2003)	Definition of comfort requirements and comfort zones in Sydney, illustration of prediction ability of study comfort indices, the need for development of a comfort index with universal application. Introduction psychological concept of alliesthesia to explain seasonal differences in thermal perceptions
Melbourne/Cfb Adelaide/BSk	Summer, typical urban spaces	Questionnaire, Measurement	Finding comfort conditions in two Australian cities	Loughnan et al. (2012)	Definition of acceptable thermal range in Melbourne (PET: 19.9˚C-23.2˚C) and Mawson Lakes (PET: 25˚C-30.6˚C)
Melbourne/Cfb	Summer, Melbourne area	Simulation, Measurement	Understanding the consequences of dense urban design on thermal conditions and comfort	d'Argent (2012)	Providing evidence to show the influence of highly dense urban development on thermal comfort conditions of Melbournians.
Melbourne/Cfb	Summer, winter, square	Questionnaire, Measurement	Identification of climate and culture background role in thermal perceptions	Kenawy (2013)	Illustration the role of culatural and climatic background on people's thermal perceptions.
Melbourne/Cfb	Summer, botanical garden(s)	Questionnaire, Measurement	Finding the specifications of thermal comfort and adaptation among visitors of botanical gardens	Lam et al. (2016)	Definition of acceptable thermal ranges for Chinese tourists (20.4-28.3 ˚C) and Australians (28.4-32.3 ˚C). Finding evidence to prove the impact of climatic background on thermal satisfaction.
Adelaide/BSk Sydney/Cfa	Spring, summer, autumn.	Questionnaire, Measurement Observation, Simulation	Investigation of urban residents' outdoor activity choices	Sharifi et al. (2017), Sharifi and Boland (2016)	Outdoor activity choices were affected significantly by the urban microclimate parameter of solar radiation. The acceptable thermal range was found (UTCI: 28 – 30 ˚C)

Except for one (de Freitas 1985), the focus of most studies in Australia was on the outdoor spaces of capital cities (Table 3.5); the metropolises with fundamental reforms in their design and development to accommodate higher residents population (Forster 2006). These spaces therefore are subject to ecological issues such as UHI (Chen et al. 2013). The early work of de Freitas (1985) aimed to discover the relationship between subjective thermal judgement and prediction of thermal responses in recreational resorts. The adequacy of comfort predictions to reflect heat stress alongside beaches was explored. Despite finding a large correlation between thermal responses and predictions, the author showed that there was a conceptual difference between thermal preference and thermal sensation causing errors in interpretation of comfort index predictions regarding thermal stressors. He argued "…*subjective evaluation of the thermal environment includes two main categories of perception, namely, thermal sensation and thermal preference. Identification of sensory states within the first category, thermal sensation, provide a verbal interpretation of thermal conditions of the body, and within the second category, a measure of the level of acceptability or degree of pleasantness associated with the sensed thermal state based on self-evaluation*" (p. 101). In fact, the author provided evidence to disprove the assumption of equality of neutral temperature and optimal temperature in recreational places. However, this finding may not be broadly generalizable as the survey population had modified thermal expectations leading to different thermal perceptions which might not be similar in normal conditions.

In a more comprehensive work done by Spagnolo and de Dear (2003), thermal comfort conditions were investigated across various urban spaces in semi-tropical Sydney. The aim was to test the applicability of indoor thermal comfort assessing techniques in outdoor conditions. This research represented a breakthrough in the field of outdoor thermal comfort; to date many thermal comfort researchers have adopted the proposed protocol for the assessment of thermal comfort since its publication (Johansson and Emmanuel 2006, Lin and Matzarakis 2008, Mahmoud 2011, Yang et al. 2014, Tung et al. 2014). Nevertheless, except for introducing the concept of alliesthesia this study failed to provide much information regarding contextual factors involved in participants' thermal perceptions. The lack of data regarding subjective perceptions in transient seasons, poor explanation for the relationship between spatial features and thermal conditions, and no definition of acceptable thermal range(s) for the survey population using index values, are other shortcomings. For the first time, Loughnan et al. (2012) determined the acceptable thermal range for two Australian capital cities, Melbourne and Adelaide. Interviewing 680 individuals, the authors defined the comfort requirements of the residents of these cities. Then they attempted to find a link between human thermal comfort and principles of Water Sensitive Urban Design for addressing ecological issues in Australian cities. However, up to the present time, there is little information reported from this work and no further details have yet been provided.

With the number of thermal comfort studies in outdoor conditions increasing, and placing an emphasis on human parameters (Brager and de Dear 1998), attention is also given to the requirements of the specific users with varying contextual factors, including those from diverse climatic backgrounds (Knez and Thorsson 2008). In light of this need, Kenawy (2013) carried out a research to understand the role of culture in perceptions of thermal conditions in Melbourne. She found that thermal perceptions between people from varied climatic backgrounds differed. This research finding is of particular importance in Australia's multicultural cities as the country seeks ways to provide social inclusion by encouraging people to be in outdoor spaces at social events, festivals and exhibitions (AECOM 2008, Arthurson and Baum 2013, Loughnan et al. 2014). The other implication related to the tourism industry whereby authorities want better knowledge about the climate for better tourism planning. Kenawy's study period was, however, limited to two days in summer and winter; this period may not reflect the large variation in weather conditions and corresponding comfort requirements in Melbourne where the weather's unpredictability is well documented (Pearce et al. 2011, BoM 2014a). The outcome could have even more insightful, particularly for the Australian tourism industry, if the study had separated those who had just arrived Melbourne from users who had stayed longer.

Identifying the gap in outdoor comfort research in Australia, Lam et al. (2016) set out to capture special comfort requirements of short-term visitors (i.e. tourists) in Melbourne's Botanical Gardens. This study involved a field survey of visitors from different countries. The researchers had indicated that "*…the multiple nationalities of visitors and the diverse microclimates inside the garden offer novel insight into the roles of various factors that affect thermal comfort perception*"(Lam et al. 2016 p. 3). The results of this study led to better management decisions for recreational places that tourists frequently visit in Australia. This study also aimed to explore the position of urban parks and gardens, as instrumental urban components, in the provision of acceptable human thermal comfort. In this theme, Sharifi et al. (2017) focused on usage pattern of urban residents in public spaces by understanding their spatial and activity preferences during heat stress conditions.

Six out of seven research projects carried out in Australia used a structured interview to collect information on personal details, thermal responses and other factors. Generally, these studies adopted different methodologies; a similar methodology would have made a cross-comparison possible on comfort data between different populations, spaces, and cities. Indeed, the changes in people's comfort conditions over a longer period can assist urban planners to plan urban open spaces better in the future. The studies used various comfort indices to predict comfort conditions including PET, UTCI, OUT-SET, and AT. Table 3.6 summarises the characteristics of comfort studies carried out in Australian cities.

The problems associated with a high rate of urbanisation in developed countries have led urban authorities to bear in mind the consequences for the urban ecosystem including thermal environment. As indicated in Chapter 2, the new urban planning seeks to reform the design of outdoor spaces in Australian capital cities to meet the increasing needs for living in there. Therefore, authorities have set out to understand the consequences of these developments prior to beginning construction work (Victorian Government 2008, The State Government of Victoria 2014). One of these plans, Melbourne 5 million @2030 (Victorian Government 2008) included the work by d'Argent (2012). This PhD research investigated the relationship between the future compact designs of Melbourne and associated thermal comfort. Using computer simulations results, she suggested that urban residents would be influenced by altering thermal conditions with a new design. However, similar to other simulation studies the results are yet to be validated by obtaining actual thermal responses; also, the contextual factors contributing to thermal adaptation need to be considered so that they match better to real world conditions.

Table 3.6. The specifications of field surveys conducted in comfort studies in Australia

Author	Season	Sensation scale	No. subjects	Index	Target population
Sharifi and Boland (2016)	Summer	N/A	N/A	UTCI	Visitors of public spaces
Lam et al. (2016)	Summer	ASHRAE 7-point scale	2198	AT, PET	Visitors of botanical garden(s) including tourists and locals

Kenawy and Elkadi (2013)	Summer and winter	ASHRAE 7-point scale	593	PET	Users of a busy Plaza
d'Argent (2012)	Summer	-	N/A	PET	Urban residents of highly urbanised areas
Loughnan et al. (2012)	Summer	ASHRAE 7-point scale	680	PMV, PET	Users of typical outdoor urban spaces
Spagnolo and de Dear (2003)	Summer and winter	ASHRAE 7-point scale	1018	PET, UTCI, OUT-SET	Users of typical outdoor and semi-outdoor spaces
de Freitas (1985)	50 days in a year	ASHRAE 9-point scale Pleasantness scale	179	STEBIDEX, HEBIDEX	Holiday makers on a beach

Despite certain sections of studies being similar, their questionnaires varied according to the study's aim. The main indicator of subjective thermal assessment, with some modifications, was the ASHRAE 7-point scale (ASHRAE 55 2010). Climatic background , a measure of adaptation, was considered in two studies (Kenawy 2013, Lam et al. 2016). Time of exposure, length of residence, alliesthesia, thermal expectations, and purpose of visit were other factors representing thermal adaptation. As shown in Table 36, regarding the target population, two studies focused on tourists as well as locals (Kenawy 2013, Lam et al. 2016), one on holiday-makers (de Freitas 1985) and two on urban residents (Spagnolo and de Dear 2003, Sharifi et al. 2017). None of these, however, provided information about the comfort requirements of students in education precincts; they also did not provide deep insights into the role of certain factors in outdoor users' thermal perceptions. Furthermore, despite including preliminary discussions in some studies (de Freitas 1985, Spagnolo and de Dear 2003), to date no study has indicated the applicability of the comfort standards in Australia. Although the focus of d'Argent (2012) was on the effect of urban design on people's thermal perceptions, existing studies did not yield any information on the role of urban design in actual thermal perceptions of outdoor users. The comfort data presented in these studies included no educational urban precinct, which have become popular in Australian capital cities.

3.7 SUMMARY

The use of outdoor environment is linked to the provision of spaces for everyday commuting, activities, and its influences on the quality of urban living. Among the determinants of the quality of outdoor environments, high priority is given to ambient climatic conditions. Therefore, it is vital to assess the quality of thermal conditions in relation to people's health and well-being. This chapter reviewed the challenges in assessment and establish the link between thermal comfort assessment and use of outdoor spaces. Reviewing the comfort literature, this chapter identified five types of thermal sensation determinants that are classified under five clusters: individual, social, physical, psychological, and policies and standards. The two main approaches to assessing thermal comfort were presented along with the findings from relevant international and Australian studies. For Australia, the review of studies conducted over the last three decades pointed out some deficiencies in the comfort research, which contributed to formulating the research aim and questions for this study. Finally, this chapter discussed the occurrence of thermal adaptation. The next chapter discusses the methodology of this study.

CHAPTER 4: METHODOLOGY

4.1 INTRODUCTION

This chapter describes the methodology used in the research. The first part explains the theoretical framework setting to operationalise the research questions. This chapter presents the characteristics of a tailor-made multi-model framework based on three theories: alliesthesia, ecological system theory, and theory of rising expectations. Subsequently, this chapter outlines the research design and approach used to establish the groundwork for particularizing the data collection methods: a series of structured interviews (questionnaire surveys), field measurements, and unobtrusive observations conducted over three seasons (spring, summer, and autumn). These methods will capture the information needed to assess and examine the interaction between users' thermal perceptions, expectations, and local outdoor thermal conditions. The specifications of measuring systems along with protocols to administer the questionnaire survey including the process of recruiting participants form another part of this chapter. Finally, this chapter presents the analysis process with specifications of analytical tests and study variables.

4.2 THEORETICAL FRAMEWORK

This section explores the theoretical foundations of this research to understand the interactions between human parameters and the outdoor built environment. A theoretical framework indicates the research direction, research design and grounds the process through which the research hypothesis is tested and questions are addressed. Among the available research frameworks, it seems that three theories - ecological systems theory (EST) (Bronfenbrenner 1992), alliesthesia (Cabanac 1971), and rising expectations (Davies 1969) – have the closest overlapping to the research aims and objectives of this study. These together form a multi-model framework providing a conceptual insight to the research objectives and respective methodology.

4.2.1 ECOLOGICAL SYSTEMS THEORY

Ecological systems theory (EST) was introduced as a conceptual model in the 1970s (Bronfenbrenner 1979), characterised as a theory in the 1980s, and frequently modified by Bronfenbrenner until his death in 2005. The EST is a greatly adaptable framework indicating there are several distinct yet interrelated factors affecting human attitude and behaviours. In other words, the EST multi-layer framework assumes that people are influenced through a set of environments that together with their personal characteristics create knowledge of the reality (Bronfenbrenner and Evans 2000). Each environment can be a special behavioural determinant for attitude and behaviour patterns which are formed through environmental constraints and opportunities, for instance physical activities in a space (Owen et al. 2004).

EST has been adopted as a theoretical framework in many studies where the main focus was on interactions between human beings (organisms) and the surrounding ecology (Ostrom 2007). Various models of EST including socio-ecological system model (SESM) have been developed in the disciplines of sociology, psychology, education and health (Stokols 1996). As a result, this framework has been used to investigate household energy consumption, behaviour and thermal comfort (Edwards and Pocock 2011), physical activity outdoors (Owen et al. 2004, Sallis et al. 2012, Hyndman et al. 2012, Mehtälä et al. 2014), public health in urban and rural environments (Kearns et al. 2007, Williams et al. 2013) and work and life balance (Pocock et al. 2014).

The initial framework suggests the influence of a series of nested environments on human behaviour, with the first environment (individual) having the greatest impact. However, it is difficult to indicate the dependence of each environment on another and to determine the precise role of each factor environment. This limitation is already identified by Ireson (2008) where the influence flow from an outlier (an environment with the least effect) to the centre (an environment with the greatest effect) was compared with the mutual direction between environments (which is proposed by the associated models). Therefore, in this study a non-nested structure and separate environments are considered. This modification in the structure of SESM would not change its function in addressing the research objectives; as system maintains its identity if the key elements and relationships are retained continually across time and space (Cumming and Collier 2005).

As indicated before and in relation to the theory of adaptive comfort there are sets of factors including thermal and non-thermal ones that can influence outdoor thermal perceptions. These factors are different in nature and should be classified in a set of clusters for ease of investigation and to understand the individual role of each cluster in the development of people's thermal perceptions (de Dear and Brager 1998, Knez et al. 2009, Shooshtarian 2015). The model can interpret analytical findings within each cluster to better understand the extent of influence of a similar set of factors on thermal perceptions. Therefore, the second research question on the effect of contextual factors can be better addressed using the SESM model. A similar organisation of thermal perception determinants in different clusters emerged in the work of Knez and Thorsson (2006) where they presented a flow of influence from clusters of ecology (incl. physical environment, climate, geography), culture cluster (incl. norms, rules, values), individual cluster (incl. attitudes, beliefs) and behaviour cluster (incl. perceptions) on outdoor thermal perceptions.

The other problem with studying outdoor thermal perceptions and usage pattern is linked to the fact that there is no limit to the number of possible influential factors. Shove (2010) indicated there exists no method to establish the history of factors, their dynamic qualities, their interdependence, and their exact impact on developing or preventing behaviours (perception) (p. 1275). Furthermore, with an increase in the number of contextual factors to the mix of comfort the more complex the picture becomes (Shove 2010). Cumming and Collier (2005) indicated that "*…it is often difficult to decide on what constitutes a given complex system, i.e., where system boundaries should be set, and what amounts to substantial change within the system*" (p. 1).

4.2.1.1 SESM environments

By investigating the implication of each SESM environment on human thermal perceptions, it was expected that findings specify the boundaries of requirements for thermal comfort in urban outdoor spaces. Figure 4.1 depicts the SESM structure which is developed for this study in order to investigate contextual factors including those clustered under each environment. This section illustrates how SESM contributed to the research approach and data collection methods. In addition to the literature review on influential factors in each environment in Chapter 3, presented below is the organisation of factors clustered in each environment, the collection methods of associated data, and the relevant discussions.

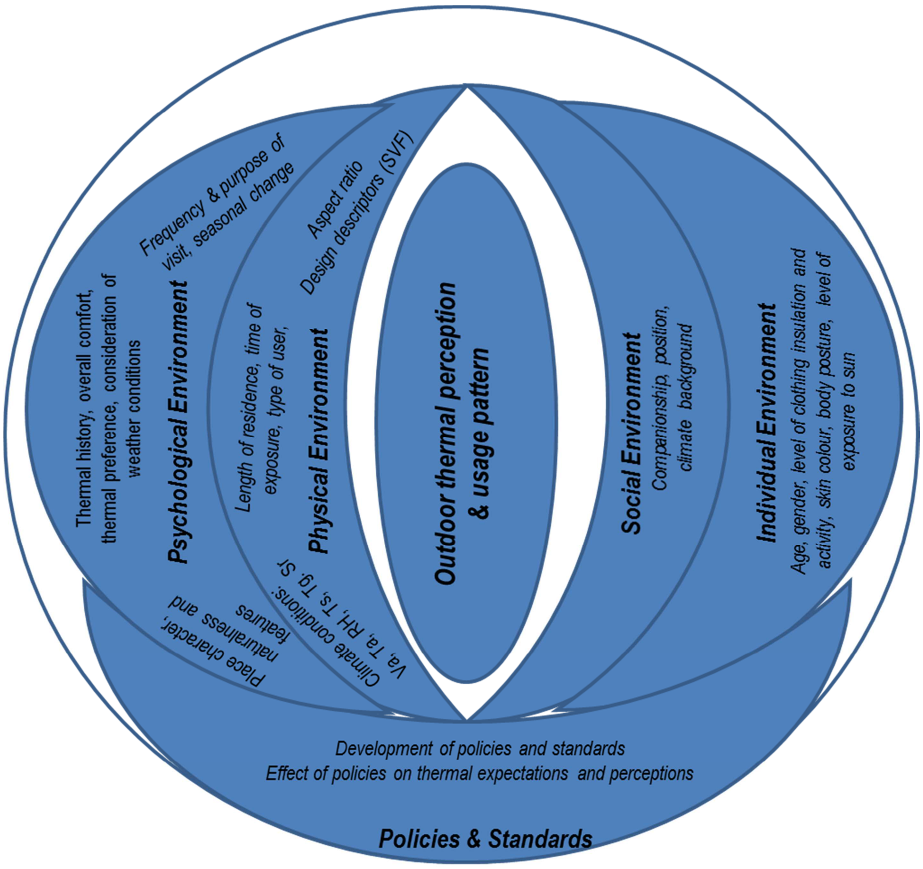


Figure 4.1. The modified socio-ecological system model and corresponding environments

Individual- in the first cluster of the SESM model the personal details are investigated. The information from this cluster helps to better understand the personal differences in response to current outdoor thermal conditions. It was also expected that the extent to which human parameters influenced perceived thermal conditions is determined. The components of this environment include age, gender, exposure to sun, body posture, skin colour, level of activity (metabolism rate) and clothing insulation (Clo value). The questionnaire survey and supplementary observations of interviewees during the field surveys provided information on individual clusters. Among the human factors investigated in this environment, participants indicated their age, gender, and level of activity, level of clothing insulation, skin colour, and users' posture. They elicited the means of supplementary observation done by the researcher.

Social environment- social environment is believed to be a contributing factor in the development of thermal perceptions in outdoor conditions (Aljawabra and Nikolopoulou 2010, Kenawy and Elkadi 2013, Maras et al. 2014, Knez and Thorsson 2008). The people's experience of the social conditions they have lived in can decide how they react to the climate. Three descriptors of the social environment used in this study were companionship, users' climatic backgrounds and position. Chapter 3 presented the summary of findings emerging from studies on the potential influence of these three components. As the case study sites are situated in a university campus, it was assumed that the observed comfort perception and pattern of usage represents the general trend in education precincts being closely interlinked with a special social environment. While the researcher determined the companionship during field surveys, participants were asked to specify their place of birth in the questionnaire.

Physical environment- the physical environment, including meteorological conditions and conditions of use, is highly regarded as a key parameter in creating thermal sensation in outdoor spaces. This environment consists of microclimate variables, design descriptor of space (SVF), thermal history, length of residence, time of exposure, and type of user. Measurement of climate parameters during the field survey provided insights into the quality of interaction between humans and thermal conditions. A number of factors including those listed above can influence this interaction in both direct and indirect ways. While the design of a space can directly influence outdoor thermal conditions, the indirect effects of users themselves and conditions in which a space is utilised can be quite impressive.

Physiological adaptation can take place in regard to quality of use of a space and indirectly influence perceived thermal sensations. As thermal adaptation may occur both in gradual and rapid ways, the study aimed to explore individuals' past and current thermal adaptation experiences under the physical environment cluster. Thermal history as an adaptive factor plays a key role in the perception of thermal conditions (Humphreys 1995). The study of thermal history can contextualise the knowledge of adaptive comfort in the geographical zone of interest and partially in similar climate conditions. However, as discussed before these factors may be classified under more than one environment and, hence, the time of exposure to an environmental stimulus and type of user (transient vs. non-transient) as both physiological and psychological constructs could also fall within the psychological environment as classified by Nikolopoulou and Steemers (2003).

Psychological environment- the psychological environment is added to the model to account for psychological parameters contributing to developing thermal perceptions of outdoor environments. A noticeably large number of studies have yielded evidence proving the role of psychological parameters in forming thermal sensations including the seminal work conducted by de Dear and Brager (1998). This led to integrating thermal adaptation into thermal comfort standards (ASHRAE 55 2010). Different mediators that are non-thermal factors and context-based can affect psychological conditions per se which in turn influence thermal perceptions. With the largest number of study factors, this environment consists of seasonal change, frequency, and purpose of visits, place character, level of naturalness, spatial features, overall comfort, preferred temperature, and consideration of weather conditions by participants before they leave home.

It is argued that seasonal changes (Spagnolo and de Dear 2003), consideration of the weather forecast, the intention and frequency of spatial use (Thorsson et al. 2007a, Pantavou et al. 2013), place character, features, naturalness (Lenzholzer and Koh 2010) and people’s overall comfort, perceived control (Nikolopoulou and Steemers 2003) and preferred temperature (Pantavou et al. 2013) can impact on people’s psychological conditions. As a result and based on what is discussed in Chapter 3, these factors mediate people’s thermal expectations and preferences (Knez et al. 2009, Chen and Ng 2012); two descriptors of thermal perceptions, that in turn affect people’s thermal perceptions. Except for checking weather forecasts before leaving home, that was collected by researcher through a separate question, these factors were investigated using responses received from participants during questionnaire surveys.

Policies and standards- in this environment the focus was on exploring the relationship between comfort standards and guidelines, and people’s perceived comfort conditions in outdoor spaces. Ideally, people are assumed to comply with standards and guidelines that are based on evidence; they try to adjust to what is prescribed in these guidelines hoping to experience better conditions. However, this might not always be the case in every context as other factors could play a larger role in how people think, perceive, act, and react. Therefore, in this environment the researcher wanted to find out whether the available comfort standards and policies have any impact on people's thermal judgement and usage pattern.

4.2.2 ALLIESTHESIA

In a seminal work on the physiological role of pleasure, Cabanac (1971) coined the term "alliesthesia" to characterise the phenomenon by which a given stimulus can create pleasant/unpleasant sensations, according to an individual's internal state. This psychological phenomenon is fundamental in negative thermal regulatory systems and it describes the processes of modification in behavioural responses (Parkinson and de Dear 2015). When the regulated variable (temperature) within the milieu interieur of these systems is diverted from its set point, any environmental impetus, being able to modify this divergence, is perceived as pleasure by an individual. For instance, water will be pleasantly tasty when one is dehydrated, but desire for water becomes a diminished pleasure to the same person when they are rehydrated. Parkinson and de Dear (2015) believed that an alliesthesia description of regulatory systems in the body entails certain dimensions: positive and negative, depending on individuals' given thermo-physiological states. In the previous example, experiencing pleasure with drinking water by a dehydrated person is "positive alliesthesia" and an indication of unpleasantness after rehydration is "negative alliesthesia".

In the context of thermal conditions the same situation applies when a person perceives a cold stimulus to be pleasant (positive alliesthesia) or unpleasant (negative alliesthesia) when his/her core temperature is, respectively, above and under normal conditions. Overall, an environmental stimulus that is responsible for restoring a regulated variable to its normal conditions (thermal set-point) is pleasant; whereas any stimulus that widens the gap (error) between that variable and its set-point is perceived to be unpleasant (Cândido et al. 2010). In an attempt to re-examine the validity of the orthodoxy of comfort theory about subjective thermal evaluation and particularly thermal neutrality, de Dear (2011) argued: "*The phenomenon of alliesthesia is used to differentiate thermal pleasure from thermal neutrality and acceptability. Alliesthesia is proposed as the logical framework of a new approach to thermal comfort modelling, building on the solid foundation of multi-node physiological models currently available in the literature*" (p. 108). Therefore, Alliesthesia could potentially present an essentially different way of considering thermal comfort.

For at least a decade, outdoor thermal comfort studies have begun to translate the implications of alliesthesia to outdoor environments to explain the effect of thermal pleasure on thermal expectations and satisfaction (see Spagnolo and de Dear (2003). Spagnolo and de Dear (2003) used this concept to explain conditions in tropical Sydney to find out why there are variations in people's thermal sensations between seasons. They pointed out that regardless of whether conditions people intrinsically yearn for higher temperature in cold seasons and vice versa in summertime. Since then, several studies employed alliesthesia to analyse the perceived comfort observed where the orthodoxy of comfort theories failed to provide an explanation (Cândido et al. 2010, Lai et al. 2014a, Krüger et al. 2015).

It is believed that the magnitude of alliesthesia is proportional to the size of load-error between the regulated variable and the normal (desired) situation (De Dear 2009), which in turn modifies people's thermal expectations. It is often assumed that a change in people's thermal expectations coincides with change in seasons when the size of load-error is found to be large in outdoor thermal conditions. This is salient for geographical zones with distinct seasons where people prefer an opposite thermal condition once they have experienced current thermal conditions enough; repeated exposure diminishes its desirability over time. This line of reasoning links the concept of alliesthesia to previous thermal experience in both short- and long-term scenarios. While the perception of thermal pleasure in the former is concerned with experiencing transient thermal conditions, the latter indicates how people are interested in having opposite weather conditions after long exposure to thermal conditions.

4.2.3 THEORY OF RISING EXPECTATIONS

The "theory of rising expectations" was coined in 1969 by James C. Davies (Davies 1969) in the science of political behaviour to describe how people's unmet rising expectations could lead to public dissatisfaction or even revolution in more extreme circumstances. This theory asserts that when there are some improvements in people's quality of life they tend to get used to it and even raise their expectations. However, according to this theory if such improvements in the same aspects or others fail to continue/happen or when there is a little control to enhance current conditions, people will never stop raising their expectations for better and still yearn for improved conditions. This trend in rising expectations creates a gap between what people expect/desire to experience and what are offered to them in the real world. This situation is more striking in developed countries where societies and governing systems are committed to maintaining high standards of living.

Applying this theory to the context of thermal comfort, this study explains how thermal expectations of a study population may vary from what they sense in outdoor thermal conditions. People in developed countries tend to spend most of their times indoors and semi-indoors including homes, residence, schools, offices, cars and public transport (Höppe and Martinac 1998, Leech et al. 2002) wherein they have control of indoor quality conditions. As indicated in Chapter 3, the economic status of communities can have a decisive role in the way people respond to outdoor weather conditions. For instance, in the context of indoor conditions thermal satisfaction was found to be linked to the match between individuals' thermal expectations of indoor climate conditions and actual thermal conditions (Fountain et al. 1996). Andamon (2005) observed that the introduction of HVAC technology to the Filipino energy market raised office occupants' thermal expectations navigated by Western consumer culture and preferences for lower temperature even though they experienced cool thermal conditions in a cool season. The participants still sought for what they assumed to be better conditions following indoor climate expectations in Western countries. This trend in raising comfort expectations is problematic particularly when there is an objective to implement the principles of adaptive thermal comfort to reduce energy costs in buildings (Roaf 2012). Knez and Thorsson (2006) stated that *"...thermal,* *emotional and perceptual assessments of a physical place may be intertwined with psychological schema-based and socio-cultural processes, rather than fixed by general thermal indices developed in line with physiological heat balance models*" (p. 254).

Further advances in technology, effective urban planning and design, and mitigation strategies have provided people with the opportunities to gain control over their outdoor thermal conditions. All these will ultimately enhance living conditions and contribute to raising people's expectations of what they want in their living environments. However, considering that some of these opportunities are expensive in terms of money and energy, it is not feasible to make them available on demand. If spatial managers fail to meet thermal expectations of people who already want a lot, it is most unlikely that they will compromise their desire for what they believe are ideal thermal conditions. There is a gap between ideal conditions (preferred temperature) and what actually eventuates (sensed temperature) in outdoors environments where there are fundamental constraints on controlling microclimate parameters. This trend is mostly evident in affluent societies or where people are financially privileged and have higher expectations relative to those living in less developed societies.

Considering the characteristics of the above-mentioned theories and models and the context of this study, three theories emerged as the most suitable ones. They could best process, analyse, interpret the ensuing findings, and address the research questions. These three are specifically: socio-ecological system model, alliesthesia and rising expectations and together they form the multi-model framework as the theoretical basis of this research.

4.3 CONCEPTUAL FRAMEWORK

A conceptual framework was developed to indicate the relationships between the concepts and variables involved in the study. The framework has five steps closely interconnected, yet independently assessed. The first step is to operationalise the study using the classifications of the study sites in order to examine them in-depth. A design descriptor, SVF, along with other spatial features were used to recognise the differences and classify the study spaces. Furthermore the climate zone classification put forward by Stewart and Oke (2012) for temperature-related studies, was applied to the case study sites (see Chapter 5).

This study used three methods of data collection: field measurement, questionnaire survey and field observation and the ensuing findings are illustrated in the five steps of the proposed conceptual framework. Figure 4.2 exhibits the conceptual framework including the three steps of data collection, their relevance to research questions, and the theories contributing to the theoretical framework of the research. Upon identification of study sites and their differences, their features (Step 1), field surveys consisting of questionnaire administrations (Step 2), field measurements (Step 3), and field observations (Step 4) began in November 2014 and lasted for 9 months, finishing in May 2015. They covered the consecutive seasons of spring, summer and autumn. The field surveys registered participants' thermal votes against climate parameters measured at the same time. The detailed descriptions of data collection methods including associated procurers and protocols are provided in the following sections.

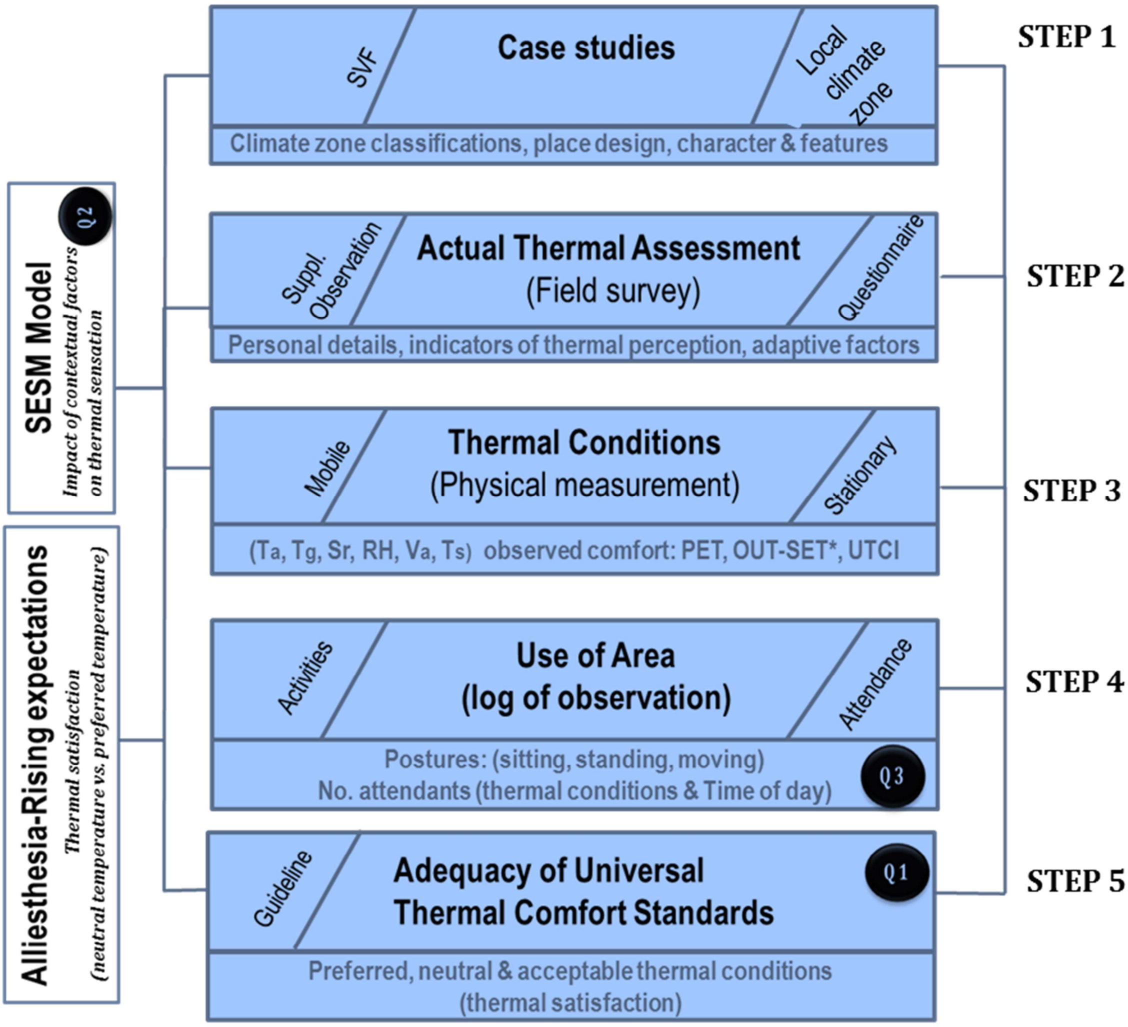


Figure 4.2. The research conceptual framework used in this study

During the three rounds of field surveys (i.e. spring, summer and autumn), the data obtained served to evaluate the role of contextual factors in the evolution of users' thermal perceptions. The effect of these factors on people's thermal sensations was further analysed by linking them to SESM model environments. As depicted in Figure 4.2, the SESM analysis addressed the second research question (effect of contextual factors on people thermal perceptions). The field survey was followed by a series of unobtrusive observations (Step 4), which aimed to understand the pattern of use in outdoor case study sites with respect to climate conditions and time of the day. Observations contributed to recognising the use of outdoor spaces in the specific environment in an urban education precinct. The findings from observations of users' attendance and activities were also interpreted in accordance to concurrent thermal conditions and contributed to addressing research question three.

In the last step of this conceptual framework (Step 5), the analytical procedures were applied to the findings obtained from the previous steps (Steps 2 and 3) to answer the first research question and test the research hypothesis, "adequacy of thermal comfort standards for application in the study context". Here, the researcher employed analytical tests to validate the assumption of equality of neutral temperature and thermal satisfaction that are enshrined in thermal comfort standards. Further, the researcher linked the results of this step to the two other components of the theoretical framework (alliesthesia and rising expectations) to interpret observed comfort conditions and justify any divergence against standards in the context of study. This step provided evidence to test the hypothesis and address the first research question. Ensuing outcomes of these steps can serve as an input to advise on effective urban planning, initiatives recommending adaptive measures in outdoor thermal conditions and to develop guidelines for future requirements of thermal comfort in education precincts in Melbourne and possibly nation-wide. Furthermore, the results are considered as a set of hands-on information for studies about climate change adaptation plans wherein the role of human parameters is central. While the results may be generalisable to contexts with similar climate conditions, they can also be a point of reference for potential comparative studies.

4.4 RESEARCH DESIGN AND APPROACH

The questions formulated for this research deal with arguments drawn from the information pertaining to comfort and usage pattern literature. This research sought to find quantitative data using a scientific and empirical approach. The meteorological conditions of an education precinct situated in a densely built up area was measured in conjunction with users' assessments of thermal conditions. A deductive approach was adopted for this study (Babbie 2015, Gill and Johnson 1991). Given the empirical nature of this research, a case study approach was selected. The descriptive characteristics of the case study sites together with the respective selection criteria are provided in Chapter 5. The case study approach allows researchers to investigate a particular subject ranging from an organisation to a group of people in more depth (Owen et al. 2004). In this regard Scholz and Tietje (2002) have remarked that the case study approach is ideal for investigating a contemporary problem within its real-life context. As indicated before comfort conditions much depend on the context including people, climate conditions, social norms, dominant culture, and available adaptive opportunities, etc., necessitating an investigation of thermal comfort in a certain context.

In terms of time horizon, this study took a transversal approach due to its proven advantages over the longitudinal one. In general the transversal approach means results show large variations and data are therefore more scattered; it provides a good estimation of study population of interest (Humphreys 1975). The disadvantages of longitudinal methods were well identified and documented (Ng and Cheng 2012, de Freitas 1985). In comfort research, de Freitas (1985) articulated that a false interpretation is likely to occur when thermal perceptions of the same participants are collected over the course of time. False interpretation is most likely linked with the risk of sample bias, which may be formed throughout an experiment. In one study which used the two approaches (Ng and Cheng 2012) it is believed that longitudinal approach has to be supplemented with a cross-sectional one to obtain the expected objectives. Also, it was noted that as a small number of people are interviewed during comfort assessment there is less likely that a wide variation in personal characteristics is captured and therefore some human parameters that are influential on thermal responses are underestimated or overlooked (Ng and Cheng 2012).

Above all, the majority of recent field surveys in outdoor comfort research has adopted the transversal approach (Johansson et al. 2014) as it has an international standing (Ng and Cheng 2012). These studies include comprehensive research projects assessing human thermal comfort in outdoor conditions to develop local guidelines and inform urban planning (Lin and Matzarakis 2008, Nikolopoulou 2011, Ng and Cheng 2012, Lamberts et al. 2013, Yang et al. 2014). For instance, the European-funded RUROS project employed transversal procedure to examine people’s thermal responses to meteorological conditions in seven European cities (Nikolopoulou 2011). Hence, taking this approach in this study makes possible a comparison between the ensuing findings and those obtained in previous seminal studies.

4.5 RESEARCH METHODS

As indicated in the conceptual framework, this study employed a number of data collection methods to investigate outdoor users' thermal preferences and expectations of microclimate conditions. Three methods proposed here were measurement and monitoring of environmental parameters, questionnaire survey, and unobtrusive observation. Collectively, these techniques are the standard practice in the assessment of outdoor thermal comfort (Nikolopoulou and Lykoudis 2006, Johansson et al. 2014). This three-stage plan was designed to achieve the aim and objectives of this study. The results obtained at each stage were statistically analysed to better understand the dynamics of achieving comfort in an education precinct in Melbourne. The full description of data collection methods including instrumentation, measurement protocols, and survey procedures are provided below.

4.5.1 PERIOD OF FIELD SURVEYS

Field surveys were carried out from 9:00 am to 17:00 pm during three seasons (spring, summer, and autumn). These times were chosen because they represent the busiest time in RUCC. Field campaign involved a total of three weeks of field survey and observation. In each season, five days were allocated to each study site to administer the survey and unobtrusive observation. Table 4.1 describes the general timeline of field surveys and observation in each season.

Table 4.1 Timeline of field surveys and unobtrusive observations

Season	Date	Duration
Spring	1st - 30th November 2014	9:00 am- 17:00 pm
Summer	1st - 30th February 2015	9:00 am- 17:00 pm
Autumn	1st - 30th May 2015	9:00 am- 17:00 pm

A special design was applied to the allocation of days to each study site with comparable thermal conditions. For this purpose, field survey in each week was equally divided between the three sites. This division made it possible to capture wider variety of climate conditions at the study sites. This strategy has been used in previous studies as a criterion to capture real-world conditions.

4.5.2 PROCESS OF RECRUITING PARTICIPANTS

Participants were university students and staff as well as the visitors from neighbouring buildings. Each participant was randomly approached and offered the chance to take part in a survey after receiving brief information on the project's objectives. The sample size was determined according to an equation suggested by Barbetta (2008). This equation (Eq. 4.1) has been used in recent outdoor comfort studies (da Silva and de Alvarez 2015, López et al. 2015, Lucchese et al. 2016) and considers 5% as the sample error.

$$\boldsymbol{n} = \frac{N \times (1/E^2)}{N + (1/E^2)}$$

Equation 4.1. Determination of sample size.

Where the N is the number of the target population (users of RUCC outdoor spaces), E is the sample error and n is the minimum number of participants for each season. According to the latest statistics from a RMIT University Property Services report (RMIT Property Services 2014), 4000 people could be potential users of these sites; therefore, a minimum of 363 answered questionnaires should be achieved in each data collection round. Each participant was assigned a code consisting of location and date of survey and a digit representing the order of interview. The time of interview was also recorded to further correspond to respective microclimate conditions. The protocol used for the field survey was approved by the RMIT University Ethics and Human Research Committee (DSC CHEAN A Project 0000018837-07/14, 19/08/2014). The invitation letter to participate in this survey is provided in Appendix A.

4.5.3 HUMAN RESPONSES

The field surveys, consisting of concurrent field measurements and structured interview, served to examine participants' comfort conditions and usage patterns. The questionnaire structure was based on comfort standards of ISO 10551 (1995), ISO 7730 (2006) along with those used elsewhere (Oliveira and Andrade 2007, Ng and Cheng 2012, Pantavou et al. 2013). The questionnaire comprised three parts: the standard questions on demographic factors (incl. age and place of birth, etc.), factors pertaining to use of outdoor spaces (incl. purpose and frequently of visit, etc.) and users' thermal perceptions (incl. thermal sensation, preference, acceptability, and overall comfort). The questionnaire contained 14 questions and its structure is presented in the Appendix A. The time needed for completing the questionnaire was 5 minutes on average. Furthermore, a supplementary observation to provide extra information was conducted to reduce the time needed for the survey and thus the rejection rate. The supplementary observation sheet is provided in Appendix A. The three main categories of information obtained from both field surveys and observations are detailed below.

4.5.3.1 Personal factors

The first set of information in the field survey pertained to personal details to elicit information on participants' demographics including their age group, place of birth, previous activity, and length of residence in Melbourne. The individuals' age were classified into 5 categories according to the age groups recommended by WHO (WHO 1982): under 18, 18-30, 31-45, 45-60, and above 60. The length of residence in Melbourne and place of birth were also acquired to understand the geographical background and familiarity (adaptation) of survey users to current climate conditions. The question on previous activity gave information about metabolic rate with options of "walking", "standing", "sitting", "sleeping", "playing/riding" and others. Additionally, the researcher recorded the participants' gender, skin colour (dark, light), position (student, staff, academic, and visitor), posture (standing, sitting, lying down), companionship (along, two people, more than two people), location of survey and ensemble clothing worn at the time of the survey through supplementary observation.

4.5.3.2 Use of the outdoor spaces

The next series of questions focused on exploring the characteristics of usage pattern among the participants. This included purpose and frequency of visit, conditions of previous thermal environment, the time of exposure to outdoor environmental parameters, their opinion about natural green spaces and attraction of place in visit, and strategies they may take in response to undesirable climate conditions. These contextual items are considered influential factors on people's thermal expectations and preference. The purpose of visit is in direct relationship with function of place. This study investigated purpose of visit using a question containing eight choices but not restricted to one option. The options were "having a break", "getting fresh air", "playing", "passage to another place", "change of environment", "having lunch/snack", "reading/writing", "meeting/waiting for someone" and other reasons. The indication of frequency of visit determined the quality of open space usage and included options ranging from "daily" to "first time" with few options in between: "several times/week", "a few times/week", "a few times/month" and "rarely".

The time of exposure to environmental parameters in outdoor spaces was indicated by four options: "less than five minutes", "5-10 minutes", "10-30 minutes" and "above 30 minutes". The previous thermal environment was also a pivotal factor in determining thermal sensation. Respondents specified their previous thermal environment (15 minutes before participation in survey) by choosing from one of the following options: "indoor non-ventilated space", "indoor ventilated space" "outdoor under shade" "outdoor under sun". The "place character" or features of space during a visit proved to have some impact on people's thermal subjective assessment (Thorsson et al. 2007a). To better understand the relationship between the place character and people's perceptions, respondents' opinions on natural green space and attraction of place were investigated. For natural green space, the options were "agreement with establishment of more natural green spaces", "no idea" and "disagreement with establishment of more natural green spaces. Furthermore, "plants and exposure to nature", "an environment with better ambient conditions" "beauty of place", "convenient of access" and other reasons apart from those stated above were the choices of place attraction. A question on possible strategies in response to undesirable weather conditions offered choices of "use umbrella/hat", "move to shade/sunlight", reduce/add clothing" and others.

4.5.3.3 Thermal perceptions

The most important part of the questionnaire survey was about people's thermal subjective assessment. Respondents' actual thermal assessments were evaluated using four perceptual indicators: thermal sensation, thermal preference, thermal acceptance, and overall comfort. For preference and acceptability there was a separation between the four environmental parameters, whereas overall comfort and thermal sensation reflected the perception of overall thermal conditions. The detailed characteristics of these indicators including the categories of each scale were provided in Chapter 2 (Section 2.5).

4.5.4 MEASUREMENT OF OUTDOOR MICROCLIMATE

To measure meteorological conditions at the case study sites, two sets of measurement were employed: the "mobile measurement system" (4.5.4.1) and "stationary measurement system" (4.5.4.2). Both systems used a combination of instruments to monitor physical aspects of environmental variations. The synoptic weather conditions were also observed throughout the study period (4.5.4.3). In the first system, mobile measurement, a few probes took the short-term measurement of environmental variables including air temperature (T_a), globe temperature (T_g), surface temperature (T_s), wind speed (V_a), relative humidity (RH) and short-wave radiation. For stationary instrumentation, sensors only monitored RH and T_a throughout the year to represent concurrent meteorological conditions of the three study sites. Mobile measurements set out to measure environmental parameters that most influence the body's heat budget and were carried out at the same time as field surveys and observations over three seasons. In the absence of outdoor thermal comfort standards, the field measurement protocol including requirements of measuring range, height and accuracy of the instruments complied with the indoor thermal comfort standards of ISO 7730 (2006) and ASHRAE 55 (2010) which was graded as "Class II". In Class II "*…field experiments in which all physical environmental variables necessary for the calculation of heat balance indices were collected at the same time and place as the thermal questionnaires were administrated, but most likely only at one height of measurement*" (Brager and de Dear 1998, p.88).

4.5.4.1 Mobile measurement

The instrumentation devised in this study monitored mentioned above. The shortwave radiation and Ts were also measured to consider other parameters affecting thermal conditions in outdoor spaces. To measure the pattern of variation in the study parameters, a Testo 480 IAQ Pro Measurement Kit was employed. Figure 4.3 displays the measurement kit employed in this study and illustrates the probes devised to monitor each variable needed to calculate thermal comfort. The portable weather station was moved around by the researcher within various points at each site every 20 minute to 1 hour. The mobile measurements lasted from 9:00 am to 5:00 pm.

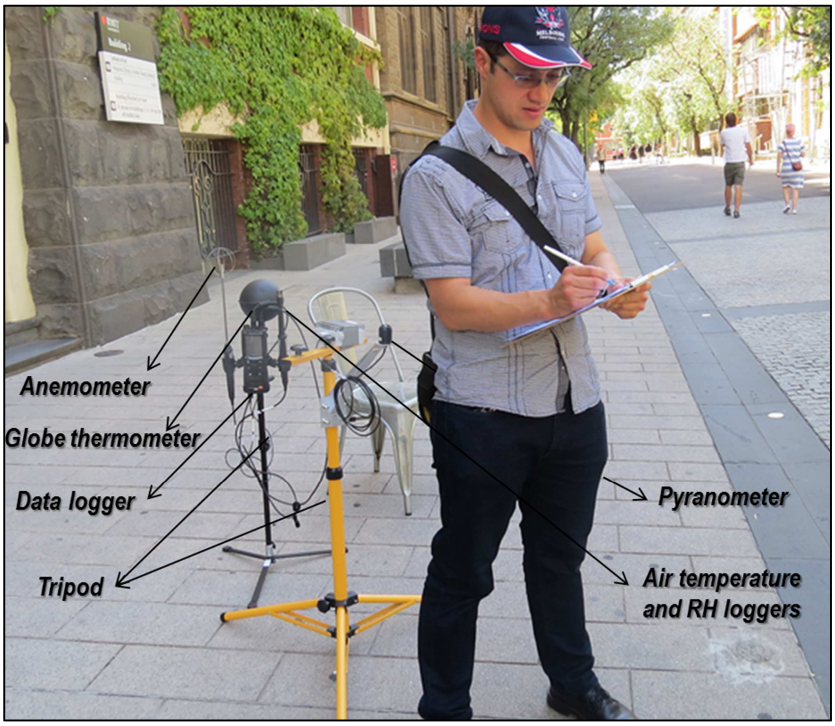


Figure 4.3. The mobile weather station used in the study.
Source: author

TESTO IAQ probe 0632 1543 containing air temperature and relative humidity data loggers monitored air temperature and relative humidity. The air temperature measuring range was 0 ˚C to 50 ˚C with an accuracy of ±0.5˚C (at temperature of 22 ˚C). Measuring range for relative humidity was 0 to +100 %RH (non-condensing) and its accuracy was ± (1.8 %RH+0.7% of meas. val.) and ±0.03 %RH/K (based on 25 ˚C). The resolution value for air temperature and relative humidity were 0.1 ˚C and 0.1%, respectively. The response time for this probe was set at 30 seconds and its height was set at 0.95 m, which is equal to body core of a sitting person. Table 4.2 summarises the specifications of the instruments deployed in the mobile measurement system.

Table 4.2. Technical specifications of instruments used in this study

Measured parameter	Height (m)	Logger	Specifications	Measuring range and response time	Accuracy and resolution
Air temperature	1.05	TESTO IAQ probe 0632 1543	IAQ probe for analysing Indoor Air Quality, CO2, humidity, temperature and absolute pressure measurement	0℃ to 50 ℃	±0.5 ℃ (at a temperature of 22℃); 0.1 ˚C
Relative humidity	1.05	TESTO IAQ probe 0632 1543	IAQ probe	0 to +100 %RH (non-condensing)	±(1.8 %RH+0.7% of meas. val.) and ±0.03 %RH/K (based on 25 ˚C); 0.1 %RH
Globe temperature	0.95	TESTO Globe thermometer 0602 0743	Black pained Globe probe Ø 150mm, TC Type K, made of copper	0˚C to +120˚C	Class 1 (-40 to +1000 ˚C); 0.1 ˚C

Air velocity	1.1	TESTO COMFORT probe 0628 0143	Omni-directional Comfort probe for degree of turbulence measurement according to EN 13779	0 to 5 m.s^{-1}	0.5 ˚C ±(0.03 m/s + 4% of meas. val.); 0.01 m.s^{-1}
Surface temperature	0.05	HOBO Pendant UA-oo1-64		-20 ˚C to +70˚C; 15 min	±0.54˚C from 0˚C to 50 ˚C: 0.1˚C at 25 ˚C
Short-wave radiation	0.95	The S-LIB-M003 Sensor	Silicon Pyranometer Smart Sensor	0 to 1280 W/m^2	Typically within ± 10 W/m^2 or ± 5%; 1.25 W/m^2

Variation in V_a was registered by TESTO COMFORT probe 0628 0143 with 0 to 5 m.s-1 measuring range. This logger is an omnidirectional anemometer measuring the wind velocity with an accuracy of ±0.5 ˚C ± (0.03 m/s + 4% of meas. val.). Omni-directional instruments are suitable for outdoor studies as the wind directions vary frequently in outdoor settings (Johansson et al. 2014), whereas one-directional anemometers can only record wind directions which are perpendicular to hot wire (ISO 7726 1998). The thermal measuring range of the anemometer was 0 ˚C to 50 ˚C (probe head) with a resolution of 0.01 m. s^{-1} and it stood at 1.1 m in height.

Globe thermometer measured T_g, which was then inserted in an equation (Eq. 4.2) to calculate T_{mrt}. Keuhn et al. (1970) and later Thorsson et al. (2007b) indicated the rationale for using T_g when calculating T_{mrt}, which represents the weighted mean of radiant and ambient temperature. TESTO Globe thermometer 0602 0743 recorded variations in T_g. This probe was basically a black painted globe with a diameter of 150 mm and made of copper standardised for indoor conditions (ISO 7726 1998). The probe's measuring range was 0˚C to +120˚C (resolution of 0.1 ˚C) with an accuracy of -40 ˚C to +1000 ˚C. In some previous literature the use of black-painted globe thermometer was questioned because it may lead to significant errors in outdoor context (Thorsson et al. 2007b, Kántor and Unger 2011, Johansson et al. 2014). These studies instead recommended the use of grey-painted globe thermometer (38 mm) which better represents the colour of individuals' clothing outdoors and has shorter response time.

In addition to T_g and T_a, the V_a values contributed to calculating the T_{mrt}. As presented below and according to comfort guidelines (ISO 7726 1998), T_{mrt} is calculated using two equations for two wind speed levels: for speeds equal or above 0.15 m.s^{-1} (Eq. 4.2) and for values below 0.15 m.s^{-1} (Eq. 4.3). As the wind speed values never dropped below the 0.15 m. s^{-1} during experiments this study used Eq. 4.3.

$$T_{mrt} = [(T_g + 273)^4 + \frac{0.25 \times 10^8}{\in}(\frac{|tg - ta|}{d})^{0.25} \times (T_g - T_a)]^{0.25} - 273$$

Equation 4.2. Computing equation for V_a above 0.15 m.S^{-1}

$$T_{mrt} = (T_g + 273)^4 + \frac{1.1 \times 10^8\, Va^{0.6}}{\in} \times (T_g - T_a)^{0.25} - 273$$

Equation 4.3. Computing equation for V_a below 0.15 m.S^{-1}

To determine T_{mrt} in respect to the human body's shape the black globe thermometer can make a good approximation for every situation (Parsons 2003). According to ISO 7726 (1998) a globe thermometer must be given 20 minutes to reach equilibrium. However, according to the results of a series of pilot experiments, the black thermometer required 10 minutes to reach equilibrium. Therefore, the TESTO weather station was left for 10 minutes in each sub-area of study sites before the questionnaire survey was implemented.

The magnitude of short-wave radiation was also captured throughout the study period. Although the measured values of this parameter were not used in prediction of thermal comfort of study sites, its effect on people's thermal perceptions was studied due to its contribution to outdoor heat budget. As depicted in Figure 4.4, a sensor (Silicon Smart HOBO S-LIB-M003) separate from TESTO IAQ kit was devised to acquire the values of short-wave radiation. This device allowed for measurement of solar radiation within the 0 and 1280 W/m^2 range with a resolution of 1.25 W/m^2. This sensor was placed on a light sensor bracket, which was screwed on an adjustable tripod at a height of 0.85 cm (Figure 4.3). The measured values in this sensor were transmitted to a separate 4-channel data logger (H21-002- HOBO Micro Station) which was strapped to the same tripod. The stepwise procedure of data readout in this study is given in 4.5.4.4.

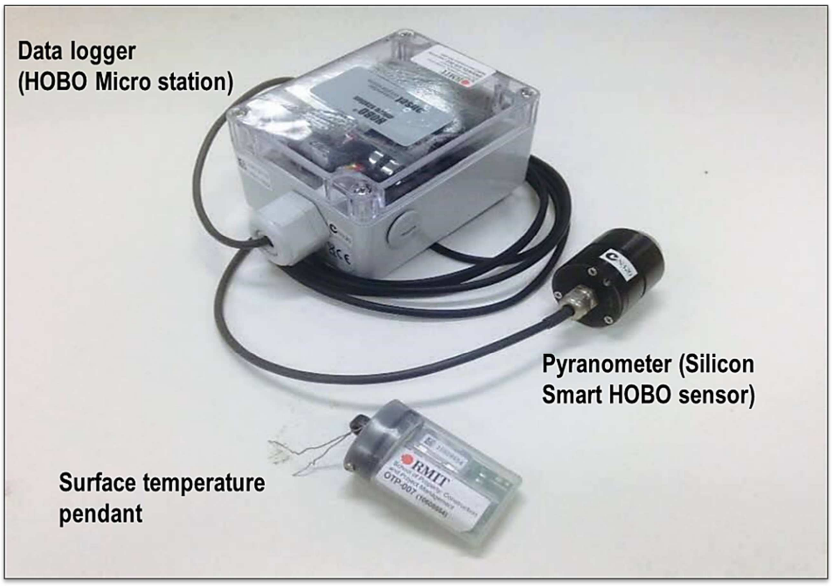


Figure 4.4. Solar radiation sensor, data logger and surface temperature pendant
Source: author

4.5.4.2 Stationary measurement

The stationary measurement system aimed to record the thermal conditions at all case study sites. It consisted of two instruments: temp-RH sensors and near surface air thermometer. Temp-RH sensors observed 24 h concurrent meteorological conditions of the three study sites and data loggers of near-surface air temperature, in short surface temperature, monitored the diurnal variation of air temperature close to different surfaces of each site on each day of measurement. Concurrent measurement of climate conditions presented the opportunity to compare meteorological readings acquired at the study sites, in order to better understand the effect of different open spaces with specific circumstances.

In order to capture air temperature and relative humidity of the study sites the HOBO Pro v2 temp/RH U23-00 was devised. The U23-001 was a waterproof data logger with built-in temperature and RH sensors. This logger can record a temperature within a range of -40˚C to 70˚C (resolution of ± 0.02 ˚C at 25˚C) and relative humidity from 0 to 100% RH (resolution of 0.03%). The specified accuracy of this probe for air temperature and relative humidity sensors was, respectively, ± 0.21˚C within the range of 0 ˚C to 50˚C and ± 2.5% within the range of 10% to 90% RH.

Furthermore, a radiation shield (RS1 Solar Radiation Shield) served to protect the sensors from direct or reflected exposure to solar radiation. This shield comprised six white painted, light weighted plates that join to form a radiation shield. One RS1 was employed at each study site in the predefined location. Figure 4.5 depicts the location of the shields in the three study sites. The selection criteria of locations were based on their representativeness of the entire site and minimal likelihood of physical damage to the sensors. The mounting heights of the sensors were, respectively, 3.3 m, 2.1 m and 3 m for sites 1, 2 and 3. The differences in heights were related to the limitations in the study sites including the occupational health and safety requirements of RMIT University.

Figure 4.5. The location of T_a/RH sensor shields in the three study sites
Source: author

As indicated in previous studies (Berg 1985, Pomerantz et al. 2000) urban surface noticeably contributes to urban heat budget. It is reported that a 1˚C change in the T_s under many circumstances can have the same influence on human thermal perceptions as a 1 ˚C change in T_a (Givoni et al. 2003). Hence, monitoring their diurnal thermal fluctuations made it possible to compare and evaluate their seasonal thermal performance in the study sites and in different seasons. This evaluation provides much data on how various surfaces contribute to the heat load in outdoor environments (Wong et al. 2003). The ground surface temperature was captured by HOBO Pendant UA-001-64 logger that could capture surface temperature within the -20 ˚C to +70˚C range (resolution 0.1˚C at 25 ˚C). For each site, four loggers were used at various points representative of different areas in these sites. The measurement accuracy of this sensor was ±0.54˚C from 0˚C to 50 ˚C. To facilitate accurate monitoring of surface temperature, a specific design was implemented. The loggers were hung from a kitchen sieve surrounding the loggers and protected them from direct exposure to sunlight. A duct tape covered the centre part of the sieve. For safety purposes, a traffic cone was placed next to the loggers to caution pedestrians of the existence of experimental devices and prevent them from stepping on them. Figure 4.6 depicts the T_s measurement instrumentation.

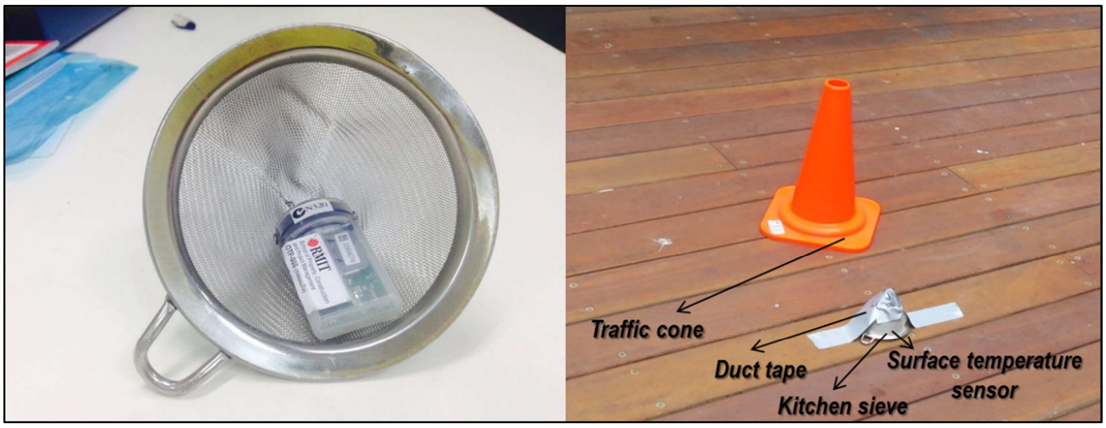


Figure 4.6. The pendent measures surface temperature and its application in the study sites. Source: author

4.5.4.3 Concurrent meteorological measurement: synoptic weather station

The outdoor meteorological observations throughout the study period were also obtained from the nearby local official weather station managed by the BOM's, Melbourne Regional Office (ID: 086071) and BOM's Melbourne Olympic Park station (ID: 086338). These two stations were, respectively, 2.5 km and 4.45 km away from the study sites, although the Melbourne Regional Office station stopped operating in January 2015. Readings taken since were acquired from the Melbourne Olympic Park station. The synoptic weather conditions observed from these stations were downloaded and compared with the monitored conditions in the case study sites.

4.5.4.4 Data Readout

Following administration of field surveys and observations on each day, the data readout was conducted to prepare the instrument for measurements next day. Date readout was carried out using two different types of software: TESTO Easyclimate Software V. 1.0 and HOBOware Pro 3.6.0. TESTO EasyClimate was run to transfer the measured values of the first physical parameters. Supporting the data readout of the sensors mentioned above, this software package can manage data, archives, and generate colour graphs. At the end of each measurement day, the measured parameters were downloaded from the TESTO 480 data logger through a plug-in head cable connected to a computer desktop.

Transferring of T_a and RH (acquired from stationary measurement system), T_s, and short-wave radiation measurement was carried out using HOBOware Pro. At the end of each season, the values of air temperature and relative humidity were downloaded from a mounted probe located under the shield using HOBO Waterproof Shuttle Part No. U-DWT-1. The shuttle was connected to a laptop to export readings and relaunch for the next round of observation. The observed data of T_s (pendant thermometer) and solar radiation (HOBO Micro Station) were transferred using the same shuttle and PC via Keyspan USB-to-Serial adapter (ADAPT-SER-USB), respectively, and ultimately the readout in HOBOware software. The readings were time stamped at 5-minute intervals and saved to Excel Spreadsheets V.10. The description of data archiving and screening is presented later in this chapter.

4.5.5 EXAMINATION OF URBAN DESIGN DESCRIPTOR

As indicated in the conceptual framework, in this study the impact of urban form was investigated using a design descriptor. It is widely used in comfort research in outdoor spaces to determine the effect of urban meteorology on people's thermal perceptions. The procedure for computation of this indicator is provided below.

4.5.5.1 Sky view factor (SVF)

Solar radiation, including short and long-wave fluxes received by outdoor users influence their energy balance. This factor was calculated by modelling the radiation fluxes through Rayman Software Package V.2.1 (Matzarakis et al. 2007). The process of modelling involved taking 180˚ fish-eye photographs of the surrounding area at each central point of the sub-spaces and to calculate SVF using Rayman. Figure 4.7 illustrates the location of the central point where the fish-eye images were taken. To consider various morphological conditions within each study site, each site was divided into four subareas. These sub-areas' centres along with the centre of the entire site were chosen for the fish-eye photograph. To take 180̊ photograph, Canon EOS 6D SLR, fitted with Canon EF 8-15 mm f/4L Fisheye USM was used. The camera was mounted on a Manfrotto 190xprob 1-meter tripod looking into the sky. The photographs taken were then imported into the "Edit free sky view factor" in the Rayman Software to calculate the SVF percentage. The average of SVF values taken in each study site was regarded as the total SVF at the given site.

Figure 4.7. Locations of central points in study sites

4.5.6 CALCULATION OF PREDICTED THERMAL COMFORT

This study employed three thermal comfort indices: PET, UTCI and OUT-SET*. These are specifically designed for outdoor conditions to predict comfort conditions of users at certain case study sites. Their specifications are documented in Chapter 2 and the calculation procedures are provided here. Rayman (Radiation on the Human Body) software package V 1.2 (Matzarakis et al. 2007) determined the PET values during the field surveys and observations. This package was developed at the University of Freiburg by Prof. Andreas Matzarakis and is programmed in English and German. This computer tool considers four environmental variables of T_a, V_a, Humidity (i.e. RH or VP) that were monitored and recorded during our experiment. The individual level of activity was assumed a constant value (80 $W.m^{-2}$ or 1.4 met) and the ensemble Clo values were based on averaged value of participants' garment insulation in each season (determined through supplementary observation during field surveys). Data and time of measurement along with geographical coordination of study spaces were also other inputs, and inserted into software to obtain precise results. All other factors remained constant to comply with the default values. The mathematical output of this program was temperature of T_{mrt} PET, PMV, SET* and UTCI values.

OUT-SET* which is an extension of SET for outdoor conditions was calculated using online software that is made publicly available by Prof. Richard de Dear from University of Sydney. This software can be accessed online at http://web.arch.usyd.edu.au/~ rdedear/. To calculate OUT-SET* this online program receives two sets of data: environmental factors and personal parameters. In order to conform to the procedure used to calculate PET, the clothing insulation values determined in field surveys were registered as the seasonal average and metabolic rate remained constant as 80 $W.m^{-2}$. In addition to computation of OUT-SET the online software generates several other indices, the more important ones being Discomfort (DISC), Thermal Sensation (TSENS), Predicted Mean Vote (PMV), Heat Stress Index (HSI) and Predicted Percentage Dissatisfied (PPD). The results also contain the extent of physiological heat stress equivalent to indices' values.

To calculate UTCI, this study used a computer freeware called Software Package BioKlima V.2.6 (Błażejczyk et al. 2013) which was developed by Prof. Krzysztof Błażejczyk and can be accessed at https://www.igipz.pan.pl/Bioklima-zgik.html. Like the other two calculators, the input data for this software are meteorological and physiological factors. For humidity, BioKlima gives the options of VP and RH; T_a and T_{mrt} are directly inserted, and wind velocities measured at 1.1 m high should be converted into air movements at 10 m high. In doing so, an equation was used to convert values of air movement at a certain height to those of interest (Aynsley et al. 1977). This equation (Eq. 4.4) as presented below assumes α as a constant value (0.30) for urban environments. V_1 and V_z are, respectively, the wind velocity measured by an anemometer mounted at 10 m high and an individual high; Z is the height of the individual and Z_1 is the height of the anemometer in use (10 m). In addition to UTCI temperature, BioKlima's final output includes a range of possible thermal indices that can be computed depending on the available input data. This program can also calculate basic statistical characteristics of input data where applicable.

$$\boldsymbol{Vz/V1} = (\boldsymbol{Z/Z1})^{\wedge} \propto$$

Equation 4.4. Converting equation for air movement values.

This study contained many analyses that are based on calculations pertaining to comfort indices, and therefore the accuracy of their predictions was tested against thermal responses described in Chapter 6. Consequently, only the comfort index with the closest predictions to thermal responses were used for further analyses in Chapters 6 and 7.

4.5.7 FIELD (UNOBTRUSIVE) OBSERVATION

The usage pattern and behaviour of the site users were also investigated using unobtrusive observations. These took place on two weekdays in each study site in each season, aiming to discover the usage patterns in RUCC open spaces. The observations, lasting from 9:00 am to 5:00 pm, were done at the same time as the physical measurement. To log users' pattern of usage and behaviour in RUCC outdoor spaces, an observation sheet was prepared which included users' attendance, their type of posture, activity, companionship and the conditions of exposure to sunlight. These factors reflected the quality of usage in different temporal, spatial and microclimate conditions. The observation sheet is shown in Appendix A.

A total of 17 observations were carried out every 30 minutes each day. The number of people who visited the site regardless of the time of stay in space was counted every 1 minute. Four postures were recorded that assumed to be naturally occurring among people who visited the study open spaces: “sitting”, “standing”, “lying down”, and “moving”. The type of activities in case study sites was also recorded in accordance with the four postures mentioned above. Hence, sitting posture referred to people who sat and had their meal, studied (reading/writing) and talked or rested. Included in the category of standing posture were talking/phoning, smoking, and eating. RUCC has had a smoke-free policy on all premises of campus since May 2014. While the moving category involved playing and passing by, the category of lying down had no sub-category. The companionship was studied by counting the number of users who attended open spaces on their own at the time of observation; companionship was only assessed between non-transient users to improve the validity of results. In the investigation of users’ reactions to microclimate parameters, particularly sunlight, where possible the number of non-transient users who spent time under sunny positions as opposed to shaded positions were registered. Cloudy days were excluded from consideration of people’s reactions to sunlight.

4.6 DATA SCREENING AND ANALYSIS

The raw data extracted from the three rounds of data collection were screened and inserted into Excel Spreadsheet V. Organisation of data was based on the participants’ codes and the date of interview divided into three seasonal categories. Included in the datasets were the values of environmental parameters (continues/scale variables), the multi-choice responses and thermal votes (categorical variables). Among the categorical variables, votes on overall comfort and thermal sensation scales were ordinal and others were nominal. The protocol of analysis in this study involved descriptive and inferential statistics. Descriptive statistics reported the analytical findings on a range of study factors extracted from field surveys and observations. The descriptive analytical findings were presented as arithmetic average, standard deviation, and distribution frequency (percentage and numerical). The descriptive analyses were presented in the form of tables and figures and comparisons were made between the categories where possible. The descriptive results are mostly presented in Chapter 6.

Inferential analyses were also employed to explain the causes of variation in study factors and to show the strength of the relationship between observed data (outcome/dependent) and influential factors (predictors/independent). In this study, the main outcome variable was people's thermal votes and the predictors were the contextual factors. This study employed five inferential analytical tests, which provided the most precise, unbiased estimates for the relationship between the observed data and statistically significant differences. These five tests were selected according to the type of study variables and whether the observed data could meet the predefined analytical assumptions thereof. These included "Probit Analysis", "Simple Regression" "Ordinal Logistic Regression", One-way Analysis of Variance (ANOVA) and "Spearman's ranked and Pearson's Correlation". The detailed characteristics of the above-mentioned test are provided below. The SPSS Software Package V. 22 (SPSS Ver. 22 2013) and Excel Spreadsheet V.10 were employed to conduct both descriptive and inferential analyses. The SPSS software is a powerful and widely used program for statistical analysis particularly in the social sciences. The figures and tables were also prepared using the same computer programs.

4.6.1 PROBIT ANALYSIS

Probit analysis was originally applied in biology to find the best application dose of commercial pesticides. Later, its application was extended to comfort research and for the first time Ballantyne et al. (1977) recommended the use of this analytical tool to compute people's neutral and preferred temperature values. This model in statistics is a type of regression where the outcome variable can only take two values, for instance comfortable or uncomfortable. Therefore, these two levels are assumed to stand either side of a central point called the intersection point; this point represents the limit in which a large number of study sample change the level. When used in the context of thermal comfort, probit analysis can determine a temperature at which a major proportion (50% or more) of participants change their thermal vote from one category to another (McIntyre 1978). The defined thermal point is known as "transient temperature" and presents a limit where there are equal probabilities of a certain thermal vote being cast for above or under a thermal sensation category (Ballantyne et al. 1977). Therefore, the associated thermal width of categories in thermal sensation scale can be determined. Accordingly, the study can specify the thermal ranges corresponding to various levels of physiological thermal stress.

In this study, the probit analysis used to calculate seasonal and overall values of neutral temperature and preferred temperature values and thermal ranges, corresponded to the categories of thermal sensation scale. As stated before in probit analysis two levels of dependent variable are needed to be defined. In the case of thermal sensation, responses were divided into levels: "warmer than neutral" and "cooler than neutral" and people's thermal preference votes were categorised as "prefer lower temperature" and "prefer higher temperature". Similarly, the thermal sensation votes were categorised as those were under and above a particular sensation category; for instance, "warmer than slightly warm" and "cooler than slightly warm". A temperature at which a line from probability of 0.5 on y-axis intersects the probit curve of thermal sensation and thermal preference is, respectively, assumed to be "neutral temperature" and "preferred temperature".

4.6.2 SIMPLE REGRESSION

Simple regression is an advanced analytical tool that seeks to understand the relationship between predictors and dependent variables. The normal distribution of a dependent variable is the main assumption and was tested here. Among the study variables, the distribution of environmental parameters and mean thermal sensation votes were found to be normal. Depending on the relationship between dependent and outcome variables, and resultant goodness of fit, linear and polynomial models of simple regression were used. The model output provides a coefficient of determination, slope coefficient and model equation.

4.6.3 LOGISTIC ORDINAL REGRESSION

Thermal perceptions of people are the main dependent variables in this research and due to the categorical nature of these variables, the associated distribution is not normal. Furthermore, due to the nature of the thermal sensation scale, the relationship between the categories is unknown. Therefore, the ordinal logistic regression is the most appropriate method for the present type of data. This model has recently been used in a number of thermal comfort studies (Pantavou et al. 2013, Aljawabra 2014, Hirashima et al. 2016a, Humphreys et al. 2015). Suggesting the use of this model in comfort research, Humphreys et al. (2015) stated that "...*Logistic Regression and Ordinal Regression may be less familiar to thermal comfort researchers but are easier to use and lead to the same results of other conventional analytical tests*" (p. 244).

The SPSS Logistic Ordinal Regression Model known otherwise as Polytomous Universal Model (PLUM) is an extension of the General Linear Model to ordinal categorical data (Pallant 2007). Included in the analytical output are estimates of goodness of fit and parameter, regression coefficient, and coefficient of determination (pseudo R-square). The estimates of goodness of fit derived from a logistic regression are maximum likelihood measures arrived at through an iterative process. The regression coefficient resulted from PLUM examines the effect size of each predictor on a dependent variable (Pallant 2007). The coefficient of determination in the logistic regression model is not equivalent to statistics for R-square. Pseudo R-square is not as useful as the statistics in other regressions, due to difficulties in their interpretation not being clear-cut (Norušis 2012). Pseudo R-square is typically expressed through three common forms: Cox and Snell-R^2, Nagelkerke's-R^2 and McFadden's-R^2.

In comfort studies, the PLUM predicts the relationship between the independent variables (both categorical and continuous) including influential factors and dependent variables (categories) such as thermal sensation under various climate conditions. In this study, the PLUM modelled the indirect relationship between SESM factors and people's thermal sensations. This relationship was established for both individual (i.e. each factor) and collective (i.e. environment) effects. The Cox and Snell Nagelkerke's R^2 was adopted to report the strength of the relationship between independent and dependent variables. Delhey and Newton (2002) have put forward a classification for values of Nagelkerke's pseudo R^2 typically referred to in the social sciences. This classification includes four levels of pseudo R^2 covering values from less than 0.033 to 0.99 and above; these are "pseudo-R^2>0.99= very strong influence", "pseudo-R^2>0.66=strong influence", "pseudo-R^2>0.033=medium influence", and "pseudo-R^2≤0.033=low influence".

4.6.4 ONE-WAY ANOVA

The one-way analysis of variances (ANOVA) was also conducted to understand the differences between thermal perceptions of two groups of people regardless of thermal conditions. ANOVA is a widely used analytical tool in comfort research and has been previously employed in several studies (Lin 2009, Taib et al. 2010, Deb and Ramachandraiah 2011, Pantavou et al. 2013, Lam et al. 2016). Since this test does not consider thermal conditions and focuses on comparative groups, it is only applied to the total dataset instead of seasonal datasets.

4.6.5 CORRELATION

Two types of correlation were used in this study given the need to analyse the association between predictors and categorical or continuous dependent variables. Pearson's correlation was selected to find the correlation between the predictor(s) and outcomes with normal distribution. Conversely, Spearman's rank correlation was employed to describe the association between continuous/categorical predictor variable(s) (independent) and a categorical outcome variable (dependent variable). The correlation outcome consists of correlation coefficient (r) and statistical significance of association (P-value). The coefficient is graded from 0 to ±1 with +1 indicating a perfect positive correlation -1 and thus a perfect negative correlation. A grading system for interpreting the correlation coefficient was used to signify the strength of the association between study variables (Pallant 2007). This grading system included six grades in each direction (negative and positive): "very strong positive/negative" (r = ±.70 or higher), "strong positive/negative" (±.40 to ±.69), "moderate positive/negative" (r=30 to ±.39), weak positive/negative (±.20 to ±.29), and no or negligible relationship (±.01 to ±.19).

4.7 SUMMARY

This chapter discussed the information on the theoretical framework used to address the main hypothesis and research questions. Subsequently, a conceptual framework is presented that expounded the relationships between different research concepts and elements including methods of data collection. For collecting data, three methods were proposed: field measurement, questionnaire survey, and unobtrusive observation. Measurement of environmental parameters was undertaken using two systems: mobile and stationary measurement. The specifications and accuracy of a range of measurements were presented; the mobile measurements protocol was Class II and complied with standards of ISO 7730 (2006) and ASHRAE 55 (2010).

For people's thermal responses, a series of questionnaire surveys was administered during three seasons; recruiting process, type of field survey (transversal) and the structure of questionnaire was described. Furthermore, the timeline of field surveys and unobtrusive observations were reported. The questionnaire consisted of 14 questions eliciting information on personal details, usage patterns, and thermal perceptions. Four indicators of thermal perceptions were overall comfort, thermal sensation, thermal preference, and thermal acceptability. The protocol of the last method of data collection, unobtrusive observation, was also presented and specified the items observed on usage pattern and behaviour during observation days in RUCC. Lastly, the analysis protocol was described and the associated analytical tools were detailed and linked back to the research objectives. Included in the analysis tests were probit analysis, single regression, ordinal logistic regression, one-way analysis of variance, and correlation. In the next chapter, the characteristics of all three study sites are provided.

CHAPTER 5: CASE STUDY SITES

5.1 INTRODUCTION

This chapter primarily describes the study context (Melbourne, Australia) and specifically the local urban climate conditions and specifications at the case study sites. The urban characteristics of the three selected study sites within RUCC are presented in detail. RUCC is situated in the heart of the Melbourne's Central Business District (CBD) which is a highly urbanised and crowded area. As a result, RUCC is subject to a range of ecological issues including UHI and increased temperature values; the thermal conditions of this area are described below. The criteria for selecting the case study sites including specific meteorological conditions of open spaces in Australian city centres, growing interest in development of education precincts, and effects of various urban characteristics on thermal conditions and perceptions were discussed. A classification system using climate zones was also employed to portray the case study sites.

5.2 MELBOURNE AND CLIMATE CONDITIONS

This study was conducted in Melbourne which has over four million people, as is known as the second largest populated city in Australia (ABS 2013). This expansion is due to immigration from overseas and rural areas and it estimated that the population will be between 6 and 8 million by 2056 (ABS 2008, Block et al. 2012). Melbourne, the capital city of Victoria, is divided into 31 Local Government areas (LGA) shaping the Melbourne Metropolitan region (Greater Melbourne). The City of Melbourne is a LGA which occupies 37 Km^2 in the Greater Melbourne area with 116,431 people and is regarded as Melbourne's economic and political centre (City of Melbourne 2012b). In Table 5.1 the statistics on population and economic conditions in the City of Melbourne explains the socio-economic conditions in the study area. These statistics reflect the encompassing densely urbanised and crowded spaces.

Table 5.1. Basic information about City of Melbourne

Item	Latest figures	Year
City of Melbourne area	37.7 km^2	2015
Estimated resident population	116,431 (p)	2013
Residential dwellings	58,395	2012
Median age	28	2011
Daytime population per day	844,000	2012
Night time (6pm – 6am) population per day (average)	378,000	2012
International visitors per year (to Metropolitan Melbourne)	1,674,612	2012
Residents born overseas	48%	2011
International tertiary student residents	26,323	2010
Most common language spoken, other than English	Mandarin 10%	2011
Total built space	29,756,430 m^2	2012
Total employment (workers)	439,172	2012
Number of establishments (business locations)	16,335	2012
Largest industry by establishments	Business Services 2764	2012
Largest industry by employment	Business Services 70,499	2012
Largest industry by floor area	Arts and Recreation 7,153,057 m^2	2012
Largest industry by commercially occupied built space	Other Services 2,279,847 m^2	2012
Number of cafe / restaurant / bistro seats	178,320	2012
Most common occupation of workers	Professionals - 40% (2006)	
Total length of roads	342 km (2011)	2011
Total area of parks / reserves	4,860,049 m^2(2012)	2012

Source: City of Melbourne (2015)

Melbourne has an Oceanic climate (Köppen-Geiger classification: Cfb) characterised by warm to hot summers and cool winters (Peel et al. 2007). Melbourne has highly changeable weather conditions due to its specific location on the borderline of the extremely hot inland region and the cool southern ocean (BoM 2014a). In summer, the minimum and maximum average air temperature reaches 16.8 ˚C and 31.9 ˚C and RH ranges from 31% up to 94%. In winter, these values are 6.5 ˚C and 14.2 ˚C for minimum and maximum average air temperature, respectively and RH averages 80%. The thermal variability is greatest in spring and summer months due to the formation of cold fronts from the northwest, west and south. The cold fronts are the cause of all the types of harsh weather conditions ranging from gales to severe thunderstorms and hail, torrential rain and sharp drops in temperature. When a cold front is passing through Melbourne, a temperature rapidly falls within the space of a few minutes and causes a shift in the direction of wind to south-westerly. This shift is attributed to cumulus clouds and showers and the cycle starts again; often cycles such as these recur on an almost weekly basis with one day or two of clear skies occurring on same days each week.

Precipitation within the city and suburbs is mostly rainfall with occasional hail and snowfall is rare. The rainfall widely varies as small as 425 ml (17 in) at Little River (37.93 30 S, 144.50 00 E) to 1,250 ml (49 in) on the eastern edge of Gembrook (37.57.00°S, 145.32 28°E) (BoM 2014a). Heavy showers can take place along with a considerable drop in temperature, which often end up traversing to calm and sunny weather having similar thermal conditions before the rainfall. As these changes occur repeatedly within a short space of time in a day, local people describe it as experiencing four seasons in one day (Pearce et al. 2011). According to climate records, Melbourne experiences frost and fog in winter and ever increasing consecutive days of extreme heat in summer (IPCC 2014). The lowest and highest temperature of Melbourne on record are -2.8 ˚C (4th July 1901) and 46.6 ˚C (7th February 2009), respectively (BoM 2014b). However, due to differences in land cover, ratio of vegetation to hard surface, topography, natural and fabricated obstacles local meteorological conditions vary across the city. The full description of Melbourne climate is provided in Chapter 6.

5.2.1 CLIMATE CONDITIONS IN MELBOURNE CITY CENTRE

The climate conditions in Melbourne city centre differ from the surrounding suburbs. The differences are mainly attributed to changes in the pattern of urban settlement that has led to changes in urban design and development to accommodate a projected population of 5 million by 2020 (Victorian Government 2008, The State Government of Victoria 2014). As shown in Table 5.1, a large proportion of this population has and will in the future have to be accommodated in the city centre.

The above mentioned changes along with a rise in anthropogenic heat production have induced a number of adverse ecological issues including urban heat island effects and increased temperature values (Coutts et al. 2007b). The occurrence of urban heat island in Melbourne city centre has been the subject of several studies (Morris and Simmonds 2000, Torok et al. 2001, Coutts et al. 2007b, d'Argent 2012, Jamei et al. 2014). Research by Morris and Simmonds (2000) in Melbourne determined a mean UHI of 3.5 ˚C from 1973 to 1991. Later on, Torok et al. (2001) observed a peak nocturnal thermal difference of 7.1 ˚C between Melbourne's CBD and the urban outskirts in 1992. A contemporary study, assessing UHI in Melbourne city centre, also identified a nocturnal UHI profile approximating to 4 ˚C in 2006 (Coutts et al. 2010). Generally, these studies suggested the formation of specific meteorological conditions in Melbourne city centre due to dense urbanisation, which may impact on people's thermal judgement and experience of visiting associated open spaces. A detailed discussion about how such urbanisation has altered meteorological conditions in Melbourne city centre is provided in the following section.

5.3 CASE STUDY SITES SELECTION

Presented below are the main rationales for selecting a university-based education precinct for assessment of thermal comfort in outdoor spaces. These include the specific meteorological conditions of densely urbanised city centres, thermal requirements of university students and staff in education precincts, and the influence of design and planning of outdoor spaces on people's thermal perceptions. While the focus of the first two criteria is placed on the importance of assessing urban precincts and particularly education precincts, the last criterion for selecting case study sites highlights the similarities and differences between them.

5.3.1 SPECIFIC METEOROLOGICAL CONDITIONS OF URBAN SPACES IN AUSTRALIAN CITY CENTRES

Melbourne has an Oceanic climate (Cfb) with highly changeable weather conditions. It also features particular meteorological conditions in its city centre areas due to the effect of fast-paced urbanisation that accommodates many people and more built up areas in its business district. The recent Australian urban planning initiatives such as Melbourne 2030 (Victorian Government 2008) and Plan Melbourne (The State Government of Victoria 2014) have recommended sustainable urbanisation by minimising urban sprawl. As indicated before, due to the shortage of appropriate land, large urban precincts are suggested as new sustainable spaces for the Australian capital cities (Randolph 2004, Forster 2006, Yigitcanlar et al. 2008). A precinct is an outdoor space surrounded by walls or other boundaries of particular built environments, or by an arbitrary and imaginary line drawn in its vicinity (Hussain 2009). A key element of Plan Melbourne is the "*expansion of central city and a series of new urban renewal precincts that will have the capacity to accommodate a large proportion of Melbourne's future housing needs close to transport and services*" (p. 7).

The RMIT University City Campus (RUCC) situated in the Melbourne central area like other open spaces in city centres is currently subject to a range of ecological issues including UHI effects caused by surrounding high-rise buildings, and densely urbanised (more hard surfaces, less evapotranspiration) and crowded spaces (higher anthropogenic heat production) (Coutts et al. 2007b, Wilkinson and Reed 2009, Chen et al. 2013). Furthermore, being integrated within Melbourne CBD and sharing the same features with open spaces in this area, the case study sites best represent the typical urban open spaces in the inner city of Melbourne and those of other Australian cities. These features included design and geometry characteristics, morphology and a surrounding environment which is densely occupied with many shops, commercial (office), residential and educational buildings, and their dominant usage pattern. The information derived from this study can contribute to the better management of and decision-making processes for outdoor spaces in Melbourne and similar conditions particularly in the face of heat waves and other ecological issues.

5.3.2 DEVELOPMENT OF EDUCATION PRECINCT IN AUSTRALIAN CITIES

With the land shortage in the city centres of Australian capital cities and a considerable growth in the number of university and Vocational Education and Training (VET) students from all around the world, education-centred precincts are most likely to be the future form of education built environments in Australia (Yigitcanlar et al. 2008, Wild-River 2013). With over 515,853 international student enrolments in 2012, Australia is one of three countries providing the most educational opportunities for international students (Australian Education International 2013). Furthermore, the successful experience of the university-centred knowledge precincts along with other urban precincts throughout Australia (Yigitcanlar et al. 2008) provides further impetus for the development of such urban spaces.

However, the possible effects of, firstly, meteorological conditions on the existing urban precincts and secondly, designs for developing new urban precincts on potential users including university students and staff should be evaluated. This evaluation has some implications for the development of guidelines and standards navigating the health and safety practices and considerations in outdoor thermal environments of education open spaces. The importance of safe thermal conditions is already highlighted in Occupation Health and Safety guidelines (OSH Service Department of Labour 1997, ASCE 2003, HaSPA 2012). To understand the foundations of thermal adaptation it is necessary to study associated non-thermal factors of users in the context of education open spaces.

Built environments are created by people to be used and inhabited by people; therefore, it is important to investigate specific requirements of potential users with the view to understanding the nature of interaction of humans and spaces. These requirements in the present case study sites can include several non-thermal factors that specifically relate to using educational outdoor built environments and can influence thermal experiences and expectations and ultimately corresponding interactions. In other words, thermal comfort conditions are user- and context-specific and depend on a range of contextual factors such as age, climate conditions, psychology and climate and cultural background (Brager and de Dear 1998, Spagnolo and de Dear 2003). As discussed in Chapter 3, several studies have indicated the importance of these contextual factors in the perception of a thermal environment and the associated interaction with outdoor built environments (Brager and de Dear 1998, Oliveira and Andrade 2007, Aljawabra and Nikolopoulou 2010, Kenawy 2013). Receiving a substantial proportion of visits from university students and staff, these case study sites provided the opportunity to determine comfort conditions for target people with roughly similar characteristics; therefore, a more valid guideline can be advised based on the findings of field surveys for education precincts. The target people on average were in the same age range and enjoyed similar usage patterns including purpose and frequency of visits. These specific considerations are not only concerned with the impacts of weather conditions on the users' health and well-being, but also contribute to enhancing academic performance.

The case study sites provide a great opportunity to investigate the influence of contextual factors on people's thermal perceptions. The particular nature of a university campus visited by people from different cultural and climatic backgrounds is a good example of a multicultural environment with varying thermal expectations and preferences. This in turn establishes the basis for evaluating culture and climate impact on people's thermal perceptions. This climate (culturally) diverse population depending on their length of stay in the study context may reveal various levels of adaptation to the prevailing thermal conditions. According to the concept of thermal adaptation (Brager and de Dear 1998, Nicol and Humphreys 2002) the longer an individual stays in certain climate conditions the better he or she can cope with given environmental stressors. Considering the extent of cultural affinity to the dominant culture, overseas university students and staff may have a different psychological state whilst staying in Australia. The psychological state can determine individuals' experiences and expectations of outdoor usage and their perceptions of thermal environment. As stated before, non-thermal factors along with the thermal factors are the determinants of people's usage of an open space. In addition, according to the adaptive paradigm, people are the active agents who respond to ambient thermal conditions and can adapt to prevailing thermal conditions. Therefore, it is suggested that plans for developing urban spaces must consider the safe conditions including less thermal hazardous spots to ensure the comfort of potential users.

The study open spaces were also developed and constantly retrofitted according to the most updated plans suggested for effective development of educational built environments such as Urban Design Guidelines Monash Technology Precinct (City of Monash 2008) and Universities Australia Good Practice Guidelines for Enhancing Student Safety (Universities Australia 2011). These guidelines promote open spaces with diverse sub-spaces in such precinct development plans. These sub-spaces offer a mix of conditions including thermal conditions to users for encouraging them to visit outdoor spaces. Accommodating a range of sub-spaces, the study open spaces in this research are good examples of the diverse spaces in university-centred education precincts. The specifications of the three open spaces are described in the following sections.

5.3.3 URBAN CHARACTERISTICS AND USERS' THERMAL EXPERIENCES AND EXPECTATIONS

The interactions of users and an outdoor space are influenced by a number of factors including physical conditions, function, and users' characteristics. The physical conditions involve the prevailing thermal conditions, design features, location and the level of access (Knez et al. 2009). Apart from physical conditions, a space possesses other dimensions that influence people's usage experiences and expectations. The concept of "place" instead of "space" which implies only physical and spatial connotations is used to accommodate the psychological and special dimensions of spatial experience (Canter 1997). Accounting for these dimensions in the assessment a certain pattern of usage behaviour or perceptions for one place can be better explained. Open spaces have been found to be well used often when they are "*...responsive to needs of users, democratic in their accessibility, and meaningful for the larger community and society*" (Francis 2003 p.1). Figure 5.1 illustrates the overview of the study sites (Site 1: University Lawn, Site 2: Ellis Court and Site 3: Urban Square).

Figure 5.1. An overview of outdoor usage in the three study sites
Note: the photos were taken in November 2014, (12:00 pm). Source: author.

In order to understand how various places with different characteristics can influence people's experiences, the above-mentioned three case study sites were selected. These cases are different in terms of character (i.e. design characteristics, function, and form), land use, type of visitors (transient/non-transient) usage, level of accessibility etc. Compared to Site 1, Site 3 and particularly Site 2 are subject to a large volume of anthropogenic heat. In Site 2 motor vehicles travelling on La Trobe Street and the energy consumption of many dwellings from surrounding high-rise buildings could potentially contribute to heat production and to a lesser extent on A'Beckett Street in Site 3. These two elements were previously found to be the main sources of anthropogenic heat production in Melbourne central (Coutts et al. 2007b, Coutts et al. 2007a). In terms of openness, the urban square (Site 3) is a rather large open space causing its visitors to experience stronger wind compared to Site 1 where the study area is an isolated space with surrounding buildings hindering air movements.

Furthermore, while Site 1 features a larger variety of urban elements including water features and natural green space offering a special microclimate to visitors, in sites 2 and 3 the majority of spaces are built with hard surfaces. Function of place is also an important feature of a space governing activities, users, and usage patterns. Since Site 2 is the main corridor of RUCC, directing people from outside the campus to education buildings, a large proportion of visitors use the space to transit to another place. This causes spatial experiences during a larger number of visits by students and staff wishing to commute between their homes, classes, and work places. However, the conditions are different in sites 1 and 3 where a noticeable percentage of visitors chose to stay and enjoy the outdoor environment by sitting in a café, meeting, exercising (playing), and having barbecues. These differences between the sites presented various opportunities for users to interact with outdoor environments. These opportunities are actually the contextual factors, which play a decisive role in forming people's thermal expectations, preferences, and usage behaviours. Ultimately, the efforts to explain the requirements of comfort conditions in these spaces contributes to the existing database of thermal comfort requirements in outdoor spaces of Australia's capital cities. The need for such a database is already identified in previous studies (Spagnolo and de Dear 2003).

5.4 RMIT UNIVERSITY CITY CAMPUS (RUCC)

RMIT University city campus is located in the Melbourne CBD (Lat: 37˚48'30.66"S Long: 144˚57'53.76"E). This area, as indicated before, is subject to a range of issues including UHI effects and adverse microclimate conditions. For instance, Melbourne' CBD experiences hot temperature values relative to the neighbouring areas. RUCC's geometry and the proliferation of impervious surfaces such as built pavements and roofs produce adverse local meteorological conditions and thermal comfort. The thermal images of the area clearly indicate the urgent need to investigate factors that play a key role in users' experience of microclimate (Coutts and Harris 2012). Figure 5.2 exhibits surface thermal conditions in Melbourne CBD. The black border lines specify the selected case study sites.

Figure 5.2. Thermal image of Melbourne CBD
Note: the RUCC and study sites are highlighted in the black square. Source: City of Melbourne (2012b).

The high surface temperature that occurs in RUCC can largely influence level of comfort conditions and thus usage of open spaces. Hence, the level of influence needs to be investigated using people's thermal perceptions and preferences. Accordingly, mitigation strategies are highly recommended to ameliorate the existing changed microclimate to enhance the users' experience outdoors.

With over 100 buildings in RMIT, RUCC accounts for above 72% of the space of all RMIT premises, student, and asset values, which have shaped it as a building-based campus. These academic buildings in the limited area have formed a university-centred education precinct. RUCC represents 6% of the Melbourne CBD area and this is equal to 6.8 hectares. The need for outdoor spaces has coincided with an increase in the number of potential users (i.e. students and staff). In line with the recent developments in RUCC outdoor areas, some efforts have been made to ensure that thermal requirements and expectations are met. For instance, in the final climate risk assessment report prepared for RMIT, urban vegetation was suggested to improve the thermal conditions in RUCC outdoors (Scott et al. 2012), and accordingly some green roofs were established (RMIT University 2012). The previously established green wall on the façade of Building 21 in RUCC is considered to be a successful example of green infrastructure, both for aesthetic and thermal adaptive purposes (City of Melbourne 2012b). In recent years, campus managers considered a temporary outdoor gazebo that can provide open space users with shade in summer and protection from high winds and rainfall in cold months.

5.5 DESIGN FEATURES OF RUCC

The study sites in RUCC differed in terms of design features and offer various opportunities to outdoor users (Table 5.2). The spatial features that are directly linked with usage of spaces are determinants of possibility and types of activities. They also represent opportunities available for users to adapt to outdoor thermal conditions as they could modify thermal conditions and provide comfortable conditions. For instance, various urban settings (i.e. water features, vegetation, shading devices) may influence users' thermal perceptions, and facilities (i.e. sitting areas, barbecues, naturalness, etc.) may alter their thermal expectations and preferences (Xi et al. 2012, Klemm et al. 2015b). As tabulated in Table 5.2, each study site is different in terms of usage pattern, available options, and vegetation, etc., which means there are varying spatial functions and character. Of the three sites, site 1 had the highest ratio of green space, which together with a linear water feature created desirable thermal conditions. The provision of facilities is a key factor to attract more people to an outdoor space. Sitting options varied across the study sites with Site 1 offering the greatest number of available sitting options followed by Site 2. The availability of seats was already found to be an influential factor on people's outdoor thermal perceptions and usage (Zacharias et al. 2004). Other options such as different spots with various sunlight conditions, water features, and green spaces can attract people and make them feel more comfortable.

Table 5.2 Summary of spatial features in the study sites

		Site 1	Site 2	Site 3
			Possible type of activities	
		sitting, walking, lying, standing, playing, reading, writing, chatting, eating, drinking, social events, meeting, outdoor learning and workshops	sitting, walking, lying, standing, reading, writing, chatting, eating, drinking, social events, meeting, outdoor learning and workshops	sitting, walking, standing, reading lying, writing, chatting, eating, drinking, walking dogs, playing, BBQ, meeting, social events, outdoor learning and workshop
			Usable sitting area	
Seat/bench	chair/steel bench	85	7	2.2
	timber bench[1]	20.6	0	226.5
	blue stone bench[1]	75.7	68	0
Seating area	total	183.4	75	22.8
(m²)	artificial turf grass	124.5	147.5	243.6
			Observed activities	
Indicators	attendance[3]	32.3	29.15	42.8
	sitting	9.7	8.2	11.5
	eating	29.7	1.7	2.3
	playing	2.1	0.1	20.9
	passing by	6	17.4	2.1
	standing	1	1.4	3.3
			Available options for thermal adaptation	
		shade trees, shading devices, water features, green space, café (food and beverages), sunny and shady spots, quick access to university's buildings (air-conditioned spaces)	shade trees, water features, sunny and shady spots, quick access to university's buildings (air-conditioned spaces)	sunny and shady spots (adjacent buildings), café (food and beverages), quick access to university's buildings (air-conditioned spaces, opportunity to park vehicles in the vicinity
			Natural vegetation	
Green space per capita		8.6	0.9	0.6
(m²/person)		45	6	6
No. of trees				

Note: 1. The bench seating capacity is assumed to be 0.75 m per person. 2. Seating areas the seating capacity is assumed to be 2 m2 per person. 3. Users' attendance averaged for the period between 10:30 am and 17:00 pm in two days of observation (30th and 31st July 2014) at 30 min intervals. Counting performed in 30 second intervals.

It is assumed that the feasibility of practicing different activities in outdoor environments could potentially influence associated usage pattern such as length of stay and frequency of visit. This has been investigated and confirmed elsewhere (Aljawabra and Nikolopoulou 2010, Nikolopoulou and Steemers 2003). Nikolopoulou and Steemers (2003) suggested that perceived control as an indicator of freedom in possible outdoor activities is a psychological mechanism of thermal adaptation that is linked with people's thermal perceptions and usage pattern. They indicated that *"… people who have a high degree of control over a source of discomfort, tolerate wide variations, are less annoyed by it, and the negative emotional responses are greatly reduced…*" (p. 97). The results showed that compared to sites 1 and 2, Site 3 had the maximum possible activities, and available options for thermal adaptation and therefore was more frequently visited during the observations. The following section elaborates more on the characteristics of these case study sites including their classification in relation to ensuing thermal conditions.

5.6 CLASSIFICATION, LOCATION AND SPECIFICATIONS OF CASE STUDY SITES

This study investigated three study sites to understand the interactions of people and outdoor built environments with respect to thermal conditions. The study sites are located in Swanston St Precinct with Site 3 covering two precincts, Market and Swanston St Precincts. Figure 5.3 shows the geographical location of each site in Melbourne's CBD; the red borderlines specify the corresponding areas. As indicated earlier, three case study sites characterise common outdoor spaces with similar urban designs and form to those of Melbourne's CBD. They also differ in terms of location, design, form, function, size, and potential users.

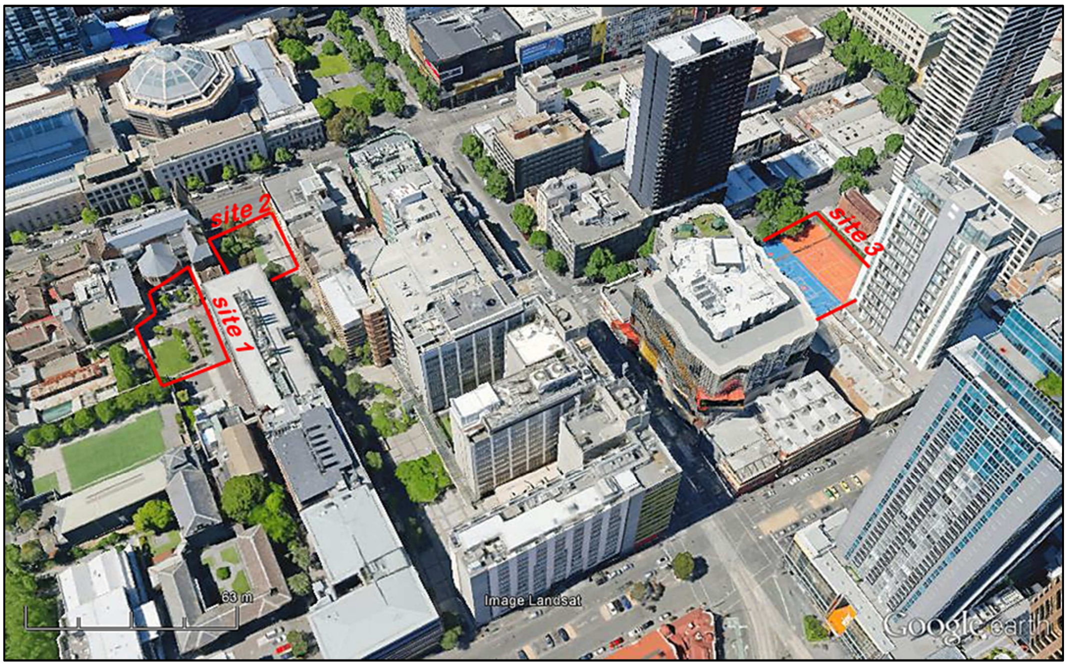


Figure 5.3. Geographical locations of study sites
Source: Imagery@2016 Google, Map data@2016 Google

Below, each study site is separately described and the characteristics of their urban forms are compared in Table 5.3. Each study site is classified using a classification (Local Climate Zones) devised by Stewart and Oke (2012). Local Climate Zone (LCZ) offers a method of classification for various urban spaces to standardise observation of urban temperature exchanges worldwide (Johansson et al. 2014). This method of classification allows for accuracy and consistency of reporting urban climate studies and is based on the physical properties of spaces including SVF, H/W and permeability fraction of surfaces.

Table 5.3. Specifications of case study sites

Item	Specifications		
	SITE 1	*SITE 2*	*SITE 3*
Site area (m^2)	1473	1302	2800
Site location and urban features	Basketball court, university lawn, café, timber deck, university way, artificial turf, garden beds, water features	Ellis Court, (part of) Bowen St, trees, AstroTurf, steel and stone chairs	Four basketball courts, table tennis table, BBQ facilities, resting areas, long timber, and steel benches and modern landscape including large planter tubs, apple crate planter boxes
Coordinates	-37.808522, 144.965	-37.808949 E 144.964808 S	-37.808535 E, 144.962126 S
Orientation, angle from true north	NW-SE, 29˚	NW-SE, 29˚	NW-SE, 29˚
SVF (0-100%)	45%	32-36%	30-32%
Mean building height (m)			
Left side:	18.2 m	25.3 m	43 m
Right side	13.0 m	18.2 m	16.1 m
Impervious surface fraction (0-100%)	52.1%	74.7%	70.5%
Pervious surface fraction (0-100%)	47.9%	25.3%	29.5%
Local Climate Zone	Compact mid-rise (LCZ_2)	Compact high-rise (LCZ_1)	Compact high-rise (LCZ_1)
Land use	Institutional, Commercial, Recreational	Institutional	Recreational

In addition to the observations on the characteristics of the case study sites, the classification results suggested differences and similarities for these sites. The similarities were orientation (NW-SE 29˚) and some urban features including surface materials. The differences were size, some urban features, SVF, local climate zone and land use. Site 3 had the biggest area (2800 m^2), followed by Site 1 (1473 m^2) and Site 2 (1302 m^2). The SVF of the study sites were quantified by calculating the ratio between obstacles and total vertical horizon using fish-eye images. The description for the procedure to compute SVF is provided in Chapter 4. In each site, five fish-eye images were taken representing the vertical conditions of sky view from the centre point of each of five sub-areas. The results showed that SVF values varied within and across the study sites with approximate magnitudes of 32% and 45%, respectively, at Sites 2 and

1. The SVF-related images and values are further presented below for each of five points in study sites. Accordingly, the physical properties of each site to LCZ classification, the study found that the following categories represent the study sites; Site 1 (compact mid-rise: LCZ_1), Site 2 (compact high-rise: LCZ_1) and Site 3 (compact high-rise: LCZ_1). According to the definitions enshrined in the urban climate classification guideline, LCZ_1 represents a dense mix of high-rise buildings of more than ten storeys high with few to no trees and with surfaces dominantly covered with pavements; and LCZ_2 is an outdoor space with a dense mix of mid-rise buildings (3-9 storeys) with few to no trees and the surfaces are mostly paved. Figure 5.4 displays the schematic built types of the two LCZs identified for RUCC open spaces (i.e. compact mid-rise and compact high-rise classes).

Local climate zone (LCZ)	Sky view factor[a]	Aspect ratio[b]	Building surface fraction[c]	Impervious surface fraction[d]	Pervious surface fraction[e]
LCZ 1 *Compact high-rise*	0.2–0.4	> 2	40–60	40–60	< 10
LCZ 2 *Compact midrise*	0.3–0.6	0.75–2	40–70	30–50	< 20

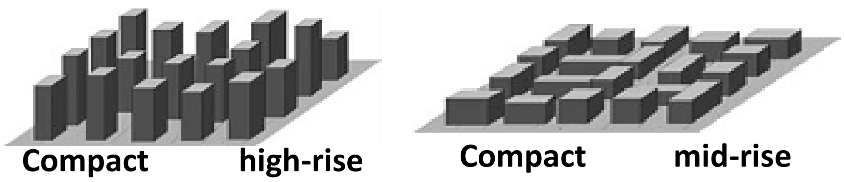


Figure 5.4. Climate zones corresponding to study RUCC open spaces.
Source: Stewart and Oke (2012)

5.6.1 SITE 1- UNIVERSITY LAWN

University Lawn (Site 1), located in RUCC, was used as a recreational space by university students and staff (Figure 5.5). Due to its compact design, a relatively prevalent form in Melbourne's built up areas, this space was an appropriate symbol of inner city Melbourne's recreational outdoor spaces. This site contained a number of urban elements including shading device in a café, timber deck and benches, water features, natural green space, and an artificially turfed area which generated varying microclimate conditions. The café served users both inside and outside and it was fitted with shading devices. This site was approached through several main and secondary entrances. There was one main pedestrian gateway through which a pathway was extended from the western side of the site to the east. This pathway merged with the traffic from Bowen Street and several school buildings close to the café and artificial lawn, and was sometimes used as a driveway for maintenance and the café. The two other pedestrian gateways were through the stairs leading to old Alumni court, which was a corridor between Buildings 1 and 3. The red lines in Figure 5.5 represent the accessible pathways in Site 1.

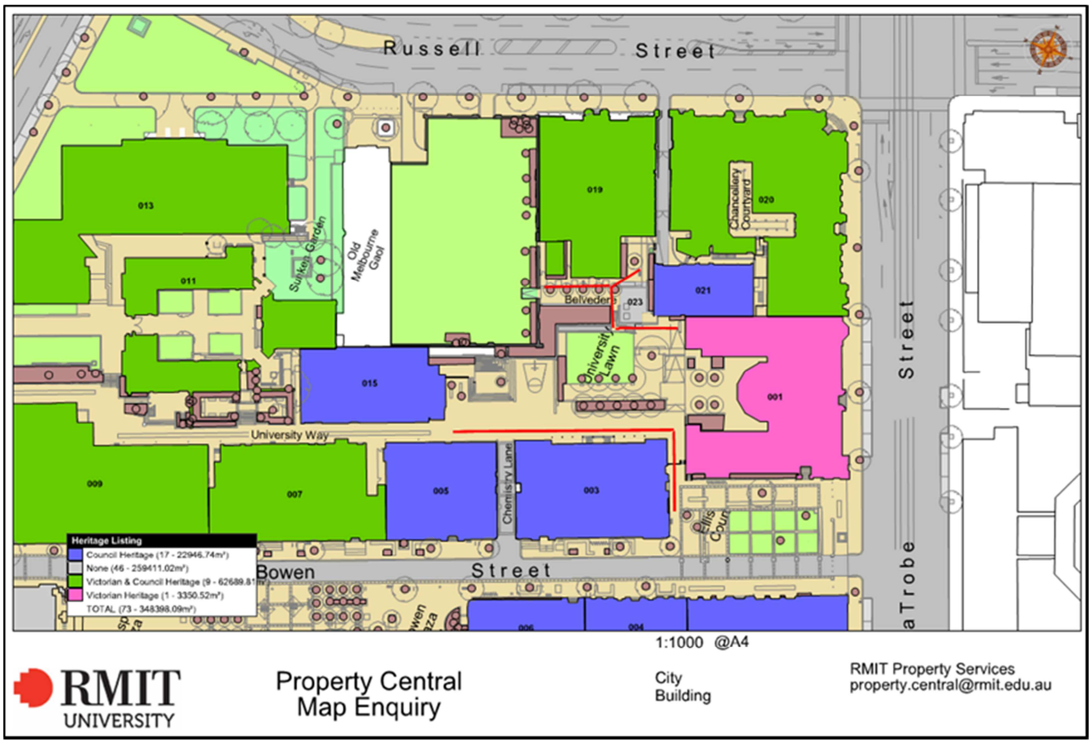


Figure 5.5. Schematic plan of University Lawn (Site 1)
Source: RMIT Property Services (2014)

As described in Chapter 4 a design descriptor (i.e. SVF) was used to assess the differences in study sites in relation to thermal conditions. The following table presents the SVF values, which are the average of values taken from the main centre point and the centre point of four quarters in Site 1 (Table 5.4). The full procedure of calculating SVF is presented in Chapter 4. The photos show how much horizon limitation there was due to obstacles. The obstacles in this site included trees, on-campus medium-sized buildings, off-campus high-rise buildings, and shading devices. Results showed a large variation in SVF values at this site ranging from 29.5% to 45.8%. This variation in SVF values was the greatest among the study sites, suggesting there were probably dissimilar local meteorological conditions in different subareas.

Table 5.4. Fish-eye photos and SVF values in Site 1

Location	Fish-eye photo	Estimated SVF value
The centre of Site 1		sky view factor: 45.8% horizon limitation: 54.2%
The centre of sub area A		sky view factor: 45.2% horizon limitation: 54.8
The centre of sub area B		sky view factor: 43.5% horizon limitation: 56.5%
The centre of sub area C		sky view factor: 29.5% horizon limitation: 70.5%

The centre of sub area D

sky view factor: 31.5%
horizon limitation: 68.4%

This site included three buildings 40 m (Building 1), 18.2 m (Building 03) and 31.6 m (Building 21) in height and they are heritage listed by the Heritage Council of Victoria. The shade in this study site was usually cast from three sources: trees, shading devices and adjacent buildings. Several surfaces had been used to this site and their coverage was classified according to their permeability. The general description of the study Site 1 and its surface coverage are tabulated in Tables 5.3 and 5.5, respectively.

Table 5.5. Analysis of surface coverage in Site 1

Permeability of surfaces		
Impervious surface	**Area (m^2)**	**Proportion (%)**
Asphalt	325.8	22.2
Bluestone paver	302	20.6
Exposed concrete aggregate	114.2	7.8
Granite cobblestone pavers	23.4	1.6
Timber	192.3	13
Total	764.9	52.1
Pervious surface	**Area (m^2)**	**Proportion (%)**
Natural green space	252	17.1
AstroTurf	224.1	15.3
Water	24	1.6
Crushed rock	10.8	0.7
Timber structure (deck)	192.3	13
Total	703.2	47.9
Shading area	**Specifications**	
Shade provided by trees	Limited shaded spots by deciduous and ever green trees	
Shade provided by shading device	Number of shading devices in the café's outdoor areas	
Shade provided by adjacent buildings	Strip shaded area cast by the adjacent buildings	

The main materials used to pave surfaces in this site, in the order of surface area (largest to smallest) were asphalt (22.2%), bluestone paver (20.6%), and AstroTurf (15.3%). The surfaces of this site were almost equally covered with impervious (52.1%) and pervious materials (47.9%). Figure 5.6 displays the main surface materials used as pavement in this site. Detailed descriptions for each of these materials including their thermal performance and behaviour are presented in Section 5.7. The measurement of surface temperature (air temperature near to surface, T_S) in this site was only carried out for the covering materials shown in Figure 5.6.

Figure 5.6. Dominant surface materials in Site 1
Source: author

5.6.2 SITE 2- ELLIS COURT

Ellis Court (Site 2) at RUCC was used for different purposes: as the main passage way to other parts of the campus, and a venue for outdoor activities and social events. This site has a 1302 m^2 area and accommodated a range of urban settings, which potentially created an outdoor space with varying local microclimate conditions. Like Site 1, this site had buildings that were heritage listed by the Heritage Council of Victoria. Due to its particular location, this site was largely frequented by students and staff during teaching hours; it is also partly occupied by them in break times. Many on campus events are conducted at the Bowen Street. Some visitors from neighbouring offices routinely used the space to relax, eat or drink, or walk through to reach other streets. This site was mainly approached from Bowen Street which extends from the western side entrance of RUCC to its eastern side. This street serves as the axis to the university buildings and pathways leading to several buildings. Its vehicular gateway was restricted by RMIT Security and permission was needed to be sought to use it. Figure 5.7 depicts the schematic plan of this site in which red lines represent the main corridor (Bowen Street) of this site used by passers-by to transit from or to education buildings.

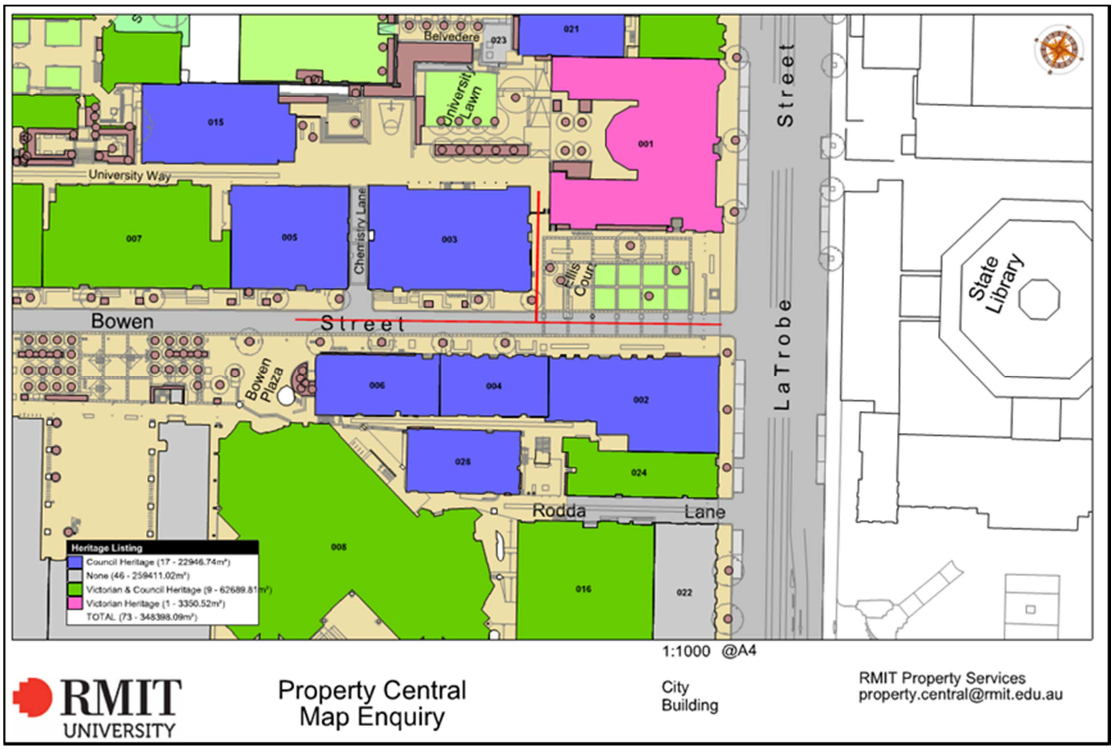


Figure 5.7. Schematic plan of Ellis Court (Site 2)
Source: RMIT Property Services (2014)

The SVF values calculated for Site 2 are presented below for the centres of space and other four sub-areas (Table 5.6). Included in the horizon obstacles here were tall trees, on campus, medium-sized buildings, and a big pole. The results emerging from computation of SVFs in Site 2 suggested many obstructions in sky view of this space. The range of variation in SVF values ranged from 20.6% at the centre of sub-area D to 36.6% at the sub-area C of the central point.

Table 5.6. Fish-eye photos and SVF values in Site 2

Location	Fish-eye photo	Estimated SVF value
The centre of Site 2		sky view factor: 33.6% horizon limitation: 66.4%
The centre of sub area A		sky view factor: 32.2% horizon limitation: 67.8%
The centre of sub area B		sky view factor: 32.8% horizon limitation: 67.2%
The centre of sub area C		sky view factor: 36.6% horizon limitation: 63.4%

The centre of sub area D

sky view factor: 20.6%
horizon limitation: 79.3%

A large turfed surface area (AstroTurf) with varying levels of exposure to sunlight was a favourite option for users during both hot and cold seasons. The sources of shade in were adjacent buildings and tall trees with broad crowns. Table 5.7 specifies the proportion of various surface materials and shading conditions in Site 2.

Table 5.7. Analysis of surface coverage in Site 2

Permeability of surfaces		
Impervious surface	**Area (m^2)**	**Proportion (%)**
Asphalt	0	0
Bluestone paver	299.9	22.7
Exposed concrete aggregate	341.9	25.9
Granite cobblestone pavers	345.3	26.1
Timber	0	0
Total	987	74.7
Pervious surface	**Area (m^2)**	**Proportion (%)**
Natural green space-garden beds	20.6	1.5
AstroTurf	268.1	20.3
Water	12.8	1
Crushed rock	3.4	0.2
Total	334.6	25.3
Shading area		**Specifications**
Shade provided by trees		Number of shaded spots provided by the tall deciduous/green trees
Shade provided by shading device		Not available
Shade provided by adjacent buildings		Heavily shaded area by the surrounding buildings

A range of materials served to cover or pave the surfaces in this site. These surfaces were largely covered with impervious materials (74.7%), including granite cobblestone pavers (26.1%), exposed concrete aggregate (25.9%) and bluestone pavers (22.7%). The main pervious surface coverage in this site was AstroTurf and it amounted to 20% of the total surface area. Figure 5.8 illustrates the dominant surface materials (i.e. exposed concrete aggregate, cobblestone pavers, AstroTurf and garden bed) used as pavement in this site. In Site 2 only T_s of the dominant surface materials was measured as shown in Figure 5.8.

Figure 5.8. Dominant surface materials in Site 2
Source: author

5.6.3 SITE 3- A'BECKKET URBAN SQUARE

RMIT A'Beckett Urban Square (Site 3) was a 2800 m^2 recreational project, which provided multi-functional courts for outdoor activities, spare modern green spaces, and shading features. This site resembled many commercial outdoor settings in Melbourne's inner city and was designed to serve a wide range of users, mainly university students, staff and other visitors. A few restaurants and cafés were near this site on Stewart Street. Building 80 was the closest educational building and students and staff from schools located in this building were typically the main users of facilities in this site. As indicated in Table 5.2, this area offered large wooden bench seats, which had different exposures to sunlight depending on the time of day. Figure 5.9 shows the schematic plan of this site extending from Swanston Street to Elizabeth Street. As represented by red lines, this site was accessible from two directions: north (Swanston Street) and west (A'Beckett Street).

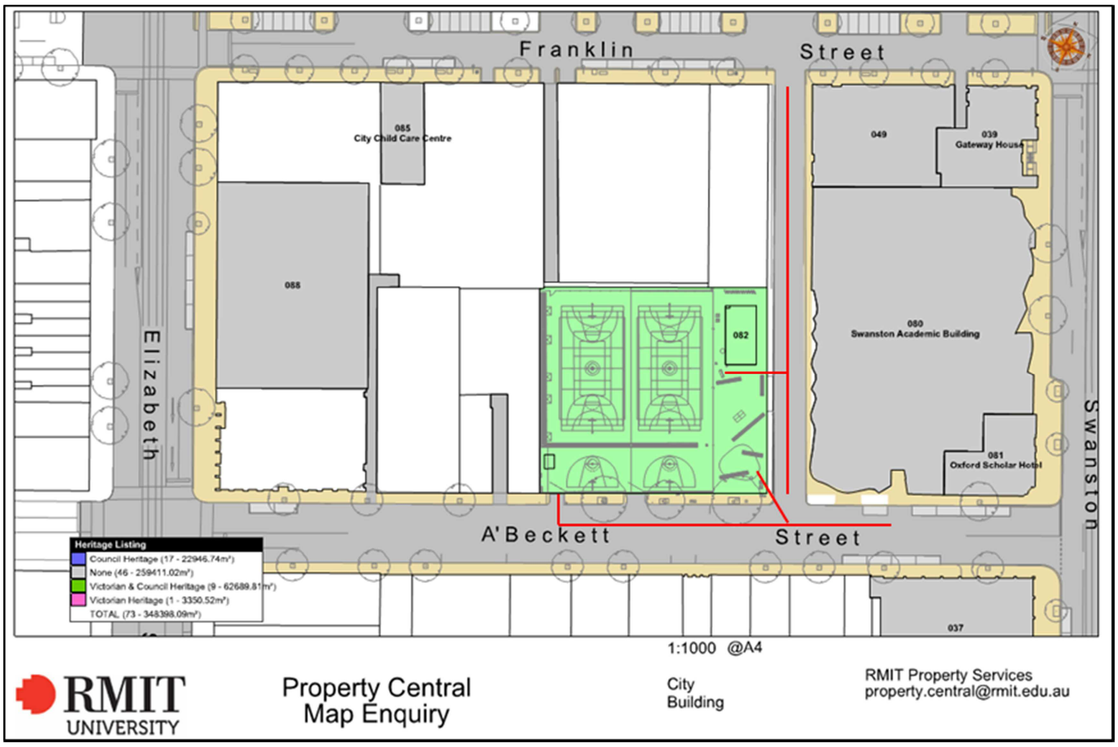


Figure 5.9. Schematic plan of Urban Square (Site 3)
Source: RMIT Property Services (2014)

Presented below are the SVF values obtained from the measurement carried out at the five points (sub-areas) in Site 3. The main obstacles in Site 3 included Swanston Academic Building 80 (43 m), surrounding high-rise offices and residential buildings (over 30 m), some medium off-site trees, and big poles. The calculated SVF values at Site 3 revealed a noticeable variation in percentage of horizon limitations among the different sub-areas. The largest percentage of SVF (45.3%) was computed for the site's central point while the smallest percentage (30.6%) belonged to central point of A.

Table 5.8. Fish-eye photos and SVF values in Site 3.

Location	Fish-eye photo	Estimated SVF value
The centre of Site 3		sky view factor: 45.3% horizon limitation: 54.7%
The centre of sub area A		sky view factor: 30.6% horizon limitation: 69.4%
The centre of sub area B		sky view factor: 36.6% horizon limitation: 63.3%
The centre of sub area C		sky view factor: 35.9% horizon limitation: 64%
The centre of sub area D		sky view factor: 31.4% horizon limitation: 68.5%

Two large and two medium-sized basketball courts (green zone) attracted many students to spend their leisure time and play sports at this site. This space contained a large turfed surface area featuring a few plant boxes of natural green spaces including small trees and ground cover. Moreover, a relatively large wooden deck was built on which people could have barbeques and social events; the aluminium structures built on this wooden deck also provided an opportunity to partly enclose the area in cases of severe climate conditions or for outdoor learning workshops.

Table 5.9. Analysis of surface coverage in Site 3

Permeability of surfaces		
Impervious surface	**Area (m^2)**	**Proportion (%)**
Asphalt	1960	70.5%
Bluestone paver	0	0
Exposed concrete aggregate	0	0
Granite cobblestone pavers	0	0
Total	1960	70.5%
Pervious surface	**Area (m^2)**	**Proportion (%)**
Natural green space-raised garden beds	26.3	1
AstroTurf	487.2	17.5%
Water	0	0
Crushed rock	0	0
Timber structure (deck)	304.2	11%
Total	817.7	29.5%
Shading area	**Specifications**	
Shade provided by trees	A small areas of basketball courts were shaded by two deciduous trees	
Shade provided by shading device	Timber deck is partly shaded by the overhanging structure	
Shading provided by adjacent built environments	Various shaded spots in the sties by surrounding high-rise buildings and walls	

Compared to other sites, this Site with the largest floor area had a limited number of surface materials. Asphalt made up more than 70% of the total covered area; indeed, hard surfaces outstripped pervious materials. Different colours on the surfaces of basketball courts contributed to heat balance with various coefficients of sunlight reflectance and absorbance. This was more tangible in summertime with intense solar radiation and could be a source of thermal discomfort. Figure 5.10 displays the major surface materials used for the surfaces of this site. Of all the surface materials utilised, only those shown in Figure 5.10 were selected to monitor changes in their T_S.

Figure 5.10. Dominant surface materials in Site 3
Source: author

5.7 MAIN SURFACE MATERIALS IN THE CASE STUDY SITES

The surfaces in RUCC were divided into two categories: pervious and impervious materials. Due to their physical nature, previous materials are able to absorb water including stormwater (Starke et al. 2010), whereas impervious materials barely absorb water. Therefore, impervious surfaces facilitate the movement of run-off. This will result in a noticeable decrease in surface evaporative cooling and increase in surface temperature. The advantages of pervious material are reviewed and presented earlier in Chapter 3 (Section 3.4.3). Presented below are the characteristics of the dominant materials used as pavement or surface coverage in RUCC. These specifications include a general description of materials in RUCC's open spaces and their thermal performance in outdoor spaces.

5.7.1 PERVIOUS MATERIALS

Pervious surfaces have recently received an increasing attention in cities and are now recognised as a solution for the adverse effects of fast urbanisation and urban heat island. In the study RUCC open spaces, three pervious surfaces existed: garden beds, AstroTurf, and timber structures (i.e. bench and deck).

5.7.1.1 Garden beds

Garden beds are established to revive lost vegetated areas caused by urbanisation in cities (Gill et al. 2007). They are ideal options to integrate natural green spaces in areas with limited spaces. Despite their environmental benefits proved in urban spaces (Tzoulas et al. 2007), some studies documented their limited application in certain circumstances (Coutts et al. 2012). As a result, to optimise their environmental performance some recommendations are made including regular irrigation particularly in hot and dry climates (Shashua-Bar et al. 2011). Except Site 1, the use of garden beds in RUCC was largely limited to narrow and raised beds with deciduous trees and sparely planted ground cover plants. These beds were filled with a medium consisting of potting mix with or without woodchips. Their medium was regularly irrigated with drip irrigation and sprinklers.

5.7.1.2 Timber structures

Timber decks have long been used for indoor and outdoor spaces as a flooring material. This material is particularly a popular option where the local sources are readily available. In addition to having an aesthetically pleasing look, they feature low thermal resistance which is a desirable characteristic in cooling local meteorological conditions (Brischke et al. 2012). Timber structures are also favoured due to their resistance to standing water as it can absorb water via its porous properties. In RUCC the use of timber took the form of deck and seat benches. Sites 1 and 3 contain both timber deck and seat benches.

5.7.1.3 AstroTurf

The application of AstroTurf in outdoor settings has become increasingly popular due to its cost effective maintenance and appealing look (Yaghoobian et al. 2010). There have been some advances in its design since it was developed in 1960; accordingly, three generations have been developed to date (City of Toronto 2015). The new generation is in-filled with a mixture of sand, recycled rubber granules and other materials. AstroTurf is generally long pile (40-65 mm) and made from polyethylene or polypropylene fibres. However, there are some environmental concerns about its adverse effects on the ecosystems of cities, including increased surface temperature (Yaghoobian et al. 2010) that could result in higher T_a and UHI (Devitt et al. 2007, Brooks 2012, City of Toronto 2015). Some areas in the RUCC open spaces are covered by AstroTurf; likewise, the three study sites all featured this covering material in relatively noticeable proportions ranging from 15% to 20% (Tables 5.5, 5.7 and 5.9).

5.7.2 IMPERVIOUS MATERIALS

Impervious materials are mostly artificial products use to pave roads, parking lots, sidewalks, and driveways, and they impede penetration of water into underground soil. The use of these materials not only imposes change in urban heat budget but also influences the ground water charge leading to increased stormwater run-off (Stone Jr 2004). Moreover, there are other environmental concerns on the extensive use of these materials in urban areas (Asaeda and Ca 2000). Despite the existence of several impervious materials in RUCC, this study only considered four dominant materials as described below.

5.7.2.1 Asphalt concrete: regular and painted

Asphalt otherwise known as bitumen is a major construction material for urban surfaces such as sidewalks, parking lots, sport courts, streets, and roads. Due to its ubiquity in urban structures, this impervious material with low emissivity and evaporation, and high albedo and heat absorbance (heat resistance) largely accounts for the urban heat budget imbalance (Berg 1985, Yilmaz et al. 2007). In RUCC, the regular and coloured asphalt concert was applied, respectively, to the sidewalk of Site 1 and basketball courts in Site 3. Compared to regular asphalt, the coloured asphalts could retain lower T_s and had small surface transfer coefficients (Berg 1985).

5.7.2.2 Exposed aggregate concrete (EAC)

Application of EAC as a pavement material improves the visual appeal in urban areas. This product is a functional concrete material with the capacity to absorb sound and noise. This material has a high thermal mass and low albedo that generates higher temperature on the surface. Of the three study sites, Site 2 had EAC as the main sidewalk surface in conjunction with bluestone and granite cobblestone.

5.7.2.3 Granite cobblestone paver

The widespread use of this material as a paver began with the ancient Romans who introduced the concept of pavements in urban areas with application of cobblestone pavers. This durable material is easy to install and requires relatively low maintenance. While it can cope with high traffic conditions it is usually laid in low traffic areas. In 2016, it was found that watering this pavement could reduce surface temperature and heat stress (Hendel et al. 2016). In RUCC, this material was used in both sites 1 and 2 as sidewalk and paver.

5.8 SUMMARY

Melbourne as the second most populated city in Australia currently experiences a high rate of population growth, migration, and fast-paced urbanisation, which have collectively influenced meteorological conditions particularly in the city centre. In general, Melbourne has an Oceanic climate with highly variable and sometimes unexpected weather conditions. Three case study sites of RMIT University City Campus

(RUCC) premises were selected to study thermal comfort requirements in the education precinct. Carrying out a comparative evaluation of these study sites, this chapter explained the differences and similarities regarding form design, spatial features, function, and the place character. Considering the "Local Climate Zone" (LCZ) classification, this chapter showed that the study sites belonged to different classes; while Site 1 was within LCZ_2 category (compact mid-rise), Site 2 and Site 3 fell within the category of LCZ_1 (compact high-rise). The utilisation of various urban surfaces and the specifications of each surface material were discussed. These materials contribute to the urban heat balance and according to their permeability, were classified into two groups: pervious and impervious. The next chapter discusses the main findings of this research, including the microclimate and thermal perceptions of this education precinct (RUCC).

CHAPTER 6: MICROCLIMATE AND THERMAL PERCEPTIONS OF THE URBAN PRECINCT

6.1 INTRODUCTION

This chapter presents the findings from the three types of data collection including on-site measurements and questionnaire surveys, and unobtrusive observations conducted in the three study sites located in RUCC. The main aim of the field surveys was to collect data to provide a thorough overview of outdoor users' profiles, the pattern of their thermal comfort perceptions and usage in three seasons (spring 2014, summer 2015, and autumn 2015). The findings together with analyses in the next chapter intend to achieve the objectives of this study. The data from the field surveys will particularly inform the discussion on the applicability of current comfort standards in the study context, aiming to investigate the research hypothesis. Evidence will be presented on how the principle assumptions enshrined in comfort standards apply to the Oceanic climate of Melbourne, Victoria. The basis of such evidence is people's thermal perception that include their thermal sensation, preference, acceptability, and overall comfort.

To better contextualise the conditions of people's thermal perception, this chapter also describes the factors having the most impact on thermal comfort, including environmental parameters and personal factors. The corresponding meteorological conditions of open spaces was measured using two measurement systems (i.e. stationary and portable), and BOM weather stations. The results of concurrent physical measurement and T_S illustrate the thermal differences between the study sites. The chapter also reports the findings obtained through observations on usage patterns in an education precinct, portraying the interaction between humans and space in various seasons. The results help address the third research question: "investigating the factors that may influence usage pattern in outdoor spaces".

6.2 CHARACTERISTICS OF PARTICIPANTS

In total, 1059 participants were interviewed in three seasons from November 2014 to May 2015. The researcher approached participants on a random basis according to the protocol approved by RMIT University Human Research Ethics Committee. Table 6.1 displays the characteristics of the participants. Upon people's acceptance to take part, the researcher briefed them on the research objectives. Each questionnaire, depending on the participants' level of English knowledge, took less than 5 minutes to complete. The researcher also advised participants that they could withdraw if any inconvenience to them was caused. To avoid bias in the findings, care was taken to ensure that the participants were chosen from both genders and all age groups.

Table 6.1. Characteristics of participants in this study

		Combined		Spring		Summer		Autumn	
		No	%	No	%	No	%	No	%
	Male	707	66.9	246	66.8	257	62.2	204	73.3
Gender	Female	352	33.1	122	33.2	156	37.8	74	26.61
	<18	30	2.8	7	1.9	20	4.8	3	1.1
	18-30	641	60.5	192	52.2	244	59.1	205	73.7
Age	31-45	254	24.0	109	29.6	102	24.7	43	15.5
	46-60	104	9.8	43	11.7	37	9.0	24	8.6
	>61	30	2.8	17	4.6	10	2.4	3	1.1
Position	Student	664	62.7	175	47.5	273	66.1	216	77.7
	Professional staff	135	12.7	56	15.2	58	14.0	21	7.6
	Academic	77	7.1	37	10.0	28	6.8	12	4.3
	Visitor	179	16.9	98	26.6	52	12.6	29	10.4
	Missing	4	0.3	2	0.5	2	0.5	0	0
Residency	Born in Mel	381	35.9	114	30.9	159	38.5	108	38
	Not born in Mel	664	62.7	249	67.6	247	59.8	168	60.4
	Missing	13	0.4	5	1.36	7	1.6	2	0. 7
Length of Residence	>1-3 months	54	5	16	4.3	28	6.7	10	3.6
	>3-12 months	77	7.3	36	9.7	20	4.8	21	7.6
	>1-3 years	54	5	29	7.8	14	3.3	11	4
	>3-10 years	223	21.1	90	24.4	73	17.6	60	21.5
	>10 years	634	60	192	52.1	271	65.6	171	61.5
	Missing	17	1.6	5	1.3	7	1.6	5	1.8
Climatic background	Tropical	187	17.7	67	18.2	64	15.5	56	20.1
	Dry	100	9.5	44	12	40	9.7	16	5.7
	Temperate	675	63.7	227	61.6	269	65.1	179	64.5
	Cold	49	4.6	29	7.9	13	3.2	7	2.5
	Missing	48	4.5	1	0.3	27	6.5	20	7.20
Body Posture	Standing	493	48.2	173	47	201	48.7	147	52.9
	Sitting	460	45.0	187	50.8	172	41.6	108	38.8
	Lying down	70	6.8	8	2.2	40	9.7	23	8.3

6.2.1 SIZE AND PROFILE OF THE SURVEY SAMPLE

Included in the survey population were males (N=704, 66.4%) and females (N=355, 33.6%) who were mostly in the 18-30 age group. The majority of participants were students (62.7%) who were mostly not born in Melbourne (63%). The study's gender distribution significantly differed from the national statistics on gender ratio in Australia (ABS 2013). Figure 6.1 illustrates the view of field surveys in RUCC study.

Figure 6.1. The field surveys in the study sites

Most participants in this study as expected were between 18 and 30 (60.5%), followed by those aged 31-45 (24%), while only a small percentage of users were under 18 and over 65, respectively (Table 6.1). This distribution pattern of age groups was observed to be rather similar in both genders. The classification of participants' age was made according to WHO (1982) in RUCC. Participants mostly possessed the standing (48.2%)

and sitting (45%) postures at the time of interview, which were rather similar in the study seasons. In terms of length of residence, the results showed that despite the particular environment of RUCC, being an international education institution, a large percentage of interviewees were born in Melbourne (35.9%) or had resided there for more than 10 years (60%). The second frequent category with more than 20% included those who had resided between one and five years in Melbourne prior to study, corresponding to the average period of an educational program in a university. Figure 6.2 shows the distribution frequency of participants' age groups and their length of residence in Melbourne.

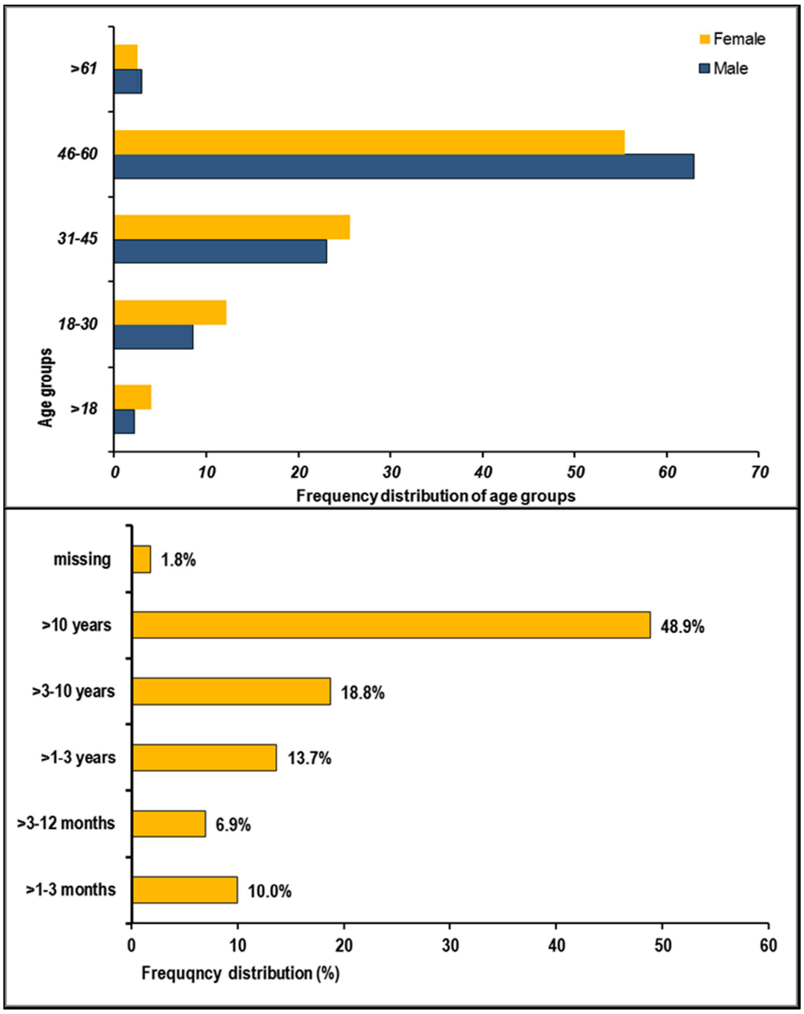


Figure 6.2. Participants' age group (top) and length of residence in Melbourne (bottom)

6.3 OUTDOOR CLIMATE CONDITIONS

To contextualise the pattern of peoples' thermal perceptions in this study, the outdoor climate conditions of study context were monitored in different seasons; the meteorological observations took place at two levels: Melbourne CBD and RUCC open spaces. For Melbourne CBD, synoptic climate conditions the measurements from BOM stations were used which where only few kilometres away. These stations monitored air temperature (T_a), relative humidity (RH), wind speed (V_a) and solar exposure (SR). The conditions of RUCC open spaces were monitored using stationary and mobile measurements. The following sections describe the specifications of measurements at the two levels.

6.3.1 MELBOURNE'S CBD CLIMATE CONDITIONS

Melbourne CBD is the most populated area in the city of Melbourne and is surrounded by a vast range of commercial, institutional and residential buildings of all types (Wilkinson and Reed 2009). Due to these specifications, the meteorological conditions differ from neighbouring areas (Coutts et al. 2013). The monthly climate conditions in the CBD during the field survey (from 9:00 am to 5:00 pm.) are presented in Table 6.2. The results showed that there was a drastic drop in T_a and solar exposure in autumn. For T_a, this drop was recorded as 8.1 ˚C and 5.8 ˚C, compared to spring and summer, respectively; this difference in the case of solar exposure was 15.1 $MJ.m^{-2}$ and 12.9 $MJ.m^{-2}$, also respectively. In terms of V_a, the observations suggested that air movement was marginally stronger in autumn (4.1 $m.s^{-1}$), compared to spring (3.2 $m.s^{-1}$) and summer (3.4 $m.s^{-1}$). The humidity data revealed an interesting pattern of change in the study seasons where RH percentage was 6.38% and 64.2% for summer and autumn, respectively, whereas this variable was only 42% in spring.

Table 6.2. Statistical information on Melbourne's climate conditions

Outdoor climate conditions	Spring	Summer	Autumn
	N=153	N=154	N=156
Ta (C°)			
Average	20.5	22.8	14.7
Std dev	4.7	3.2	1.9
Min	13.7	16.8	9.9
Max	32.8	31.9	19.8
Va (m.s⁻¹)			
Average	3.17	3.42	4.08
Std dev	1.22	1.29	1.27
Min	0.00	0.00	1.11
Max	5.55	6.11	7.77
RH (%)			
Average	42	64.1	63.8
Std dev	12	12.2	13.5
Min	17	31	41
	71	94	92
SR (MJ.m⁻²)			
Average	22.2	20	7.1
Std dev	1.4	1.3	2.1
Min	2.4	4.7	3.2
Max	29.9	28.8	12.1

Source: BOM's stations (2014-2015).

To understand if the study period represented typical seasons in Melbourne its average maximum of T_a was compared to that for the last five years (November 2009 until November 2014). The measurements were acquired from BOM Melbourne Regional Office station (ID: 086071) and BOM Melbourne Olympic Park Station (ID: 086338). In 2014, Melbourne Regional Office station ceased functioning and since then observed data was received from BOM Melbourne Olympic Park Station. However, the entire data on monthly global exposure was derived from BOM Melbourne Olympic Park Station. Figure 6.3 (top) superimposes the diurnal trend of change in thermal conditions during the field study onto that of the previous five years. As shown in this figure, there was not much difference in monthly data between those periods. The slight difference found between the two trend lines is attributed to observations obtained from the two different stations. The monthly value of SR was also compared in the two periods (Figure 6.3, below); as opposed to the last five years prior to the study. Results from November 2014 to May 2015 displayed a slightly stronger SR in spring (22.2 $MJ.m^{-2}$) relative to summer (20.9 $MJ.m^{-2}$). However, the SR equally amounted to the lowest rate in autumn in the two periods (7.4 $MJ.m^{-2}$ and 7.5 $MJ.m^{-2}$). The comparative results confirmed that that the study seasons resembled typical climate conditions in Melbourne's CBD.

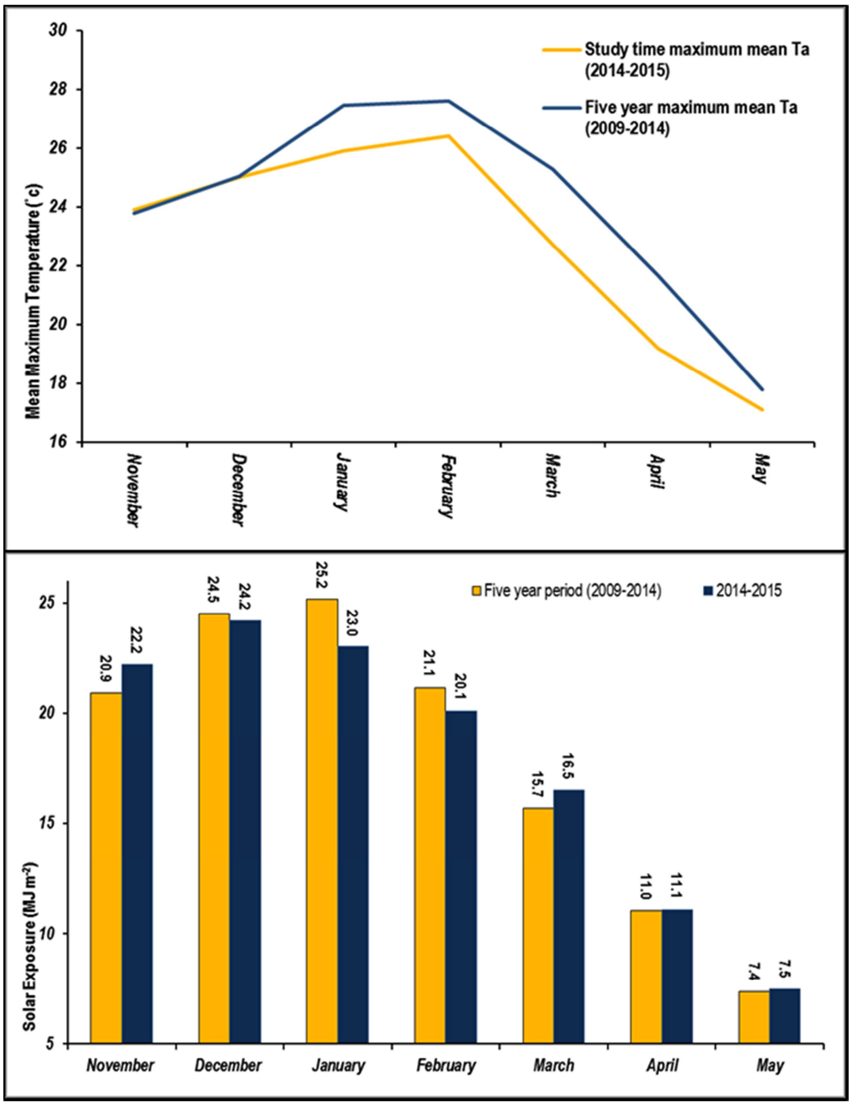


Figure 6.3. Comparison of mean monthly maximum T_a (top) and SR (below) between a five-year period (2009-2014) and study time (top)
Note: due to discontinuation of BOM Melbourne Regional Office operation, the observations from November 2015 to May 2015 were acquired from BOM Melbourne Olympic park (ID: 086338)

6.3.2 METEOROLOGICAL CONDITIONS OF RUCC USING STATIONARY SYSTEM

The second level of evaluating microclimate as indicated before is concerned with monitoring thermal conditions in RUCC's open spaces. The specifications of the measuring protocol and study sites are shown in Chapters 4 and 5, respectively. The stationary measuring system provided an opportunity to compare concurrent thermal conditions (T_a and RH) between the sites. Table 6.3 comprises the basic statistics on seasonal meteorological conditions in RUCC study sites. The results suggested that on average there is no significant disparity in overall thermal conditions among the sites throughout the study period, whereas noticeable seasonal differences were observed in thermal conditions between the seasons. In autumn (May 2015), the results of measuring T_a showed a sharp drop approximating to 14.5 ˚C in study sites, which was 8.5 ˚C and 6.5 ˚C lower than that in summer (February 2015) and spring (November 2014), respectively. The results agreed with the observations of BOM stations.

Table 6.3. Summary of seasonal climate conditions in RUCC open spaces

Outdoor climate conditions	Spring (November 2014)			Summer (February 2015)			Autumn (May 2015)		
	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
Air temperature (˚C)									
Average	20.7	19.5	20.0	23.7	22.9	22.8	14.7	14.6	14.5
Std dev	3.9	3.4	4.2	4.0	4.0	4.3	2.0	2.0	2.0
Min	15.5	15.1	15.1	17.2	16.8	16.3	9.8	9.6	9.4
Max	30.2	26.5	29.8	31.7	31.3	31.1	19.1	19.1	19.0
Relative humidity (%)									
Average	52.7	55.5	54.1	57.6	60.0	59.9	66.3	65.8	65.7
Std dev	13.0	13.3	13.3	12.0	12.8	12.7	7.9	7.6	7.3
Min	32.3	32.0	31.4	29.4	29.5	29.5	54.1	53.7	54.7
Max	87.3	86.7	85.0	83.7	84.2	83.5	82.8	82.2	83.2

Note: Source: stationary measurement

To further examine the differences in microclimate between the study sites, the trend of seasonal variations in diurnal T_a and RH values was plotted in Figure 6.4. Despite having a similar pattern in change of thermal conditions, overall the study open spaces were subject to a larger thermal disparity in the measured variables (T_a and RH) in different hours. This disparity was at its peak in warmer seasons (spring and summer) when sites 2 and 3 were slightly cooler but less humid than Site 1. This difference might be in relation to the smaller total area of Site 1 and the greater extent of enclosure that offers limited space for air circulation and potentially reduced wind speed. However, as the wind speed was not registered in stationary measurement there is no practical evidence to prove it. Higher percentage of air humidity in Site 1 was also attributed to its urban configuration including water features and larger natural green spaces that together contributed to more air humidity. The greater thermal differences in warmer seasons related to the larger variations in weather conditions as whole; the standard deviation of RH and T_a was markedly greater in these two seasons (see Table 6.3). Figure 6.4 displays the concurrent microclimate readings of RH and Ta in different sites and season.

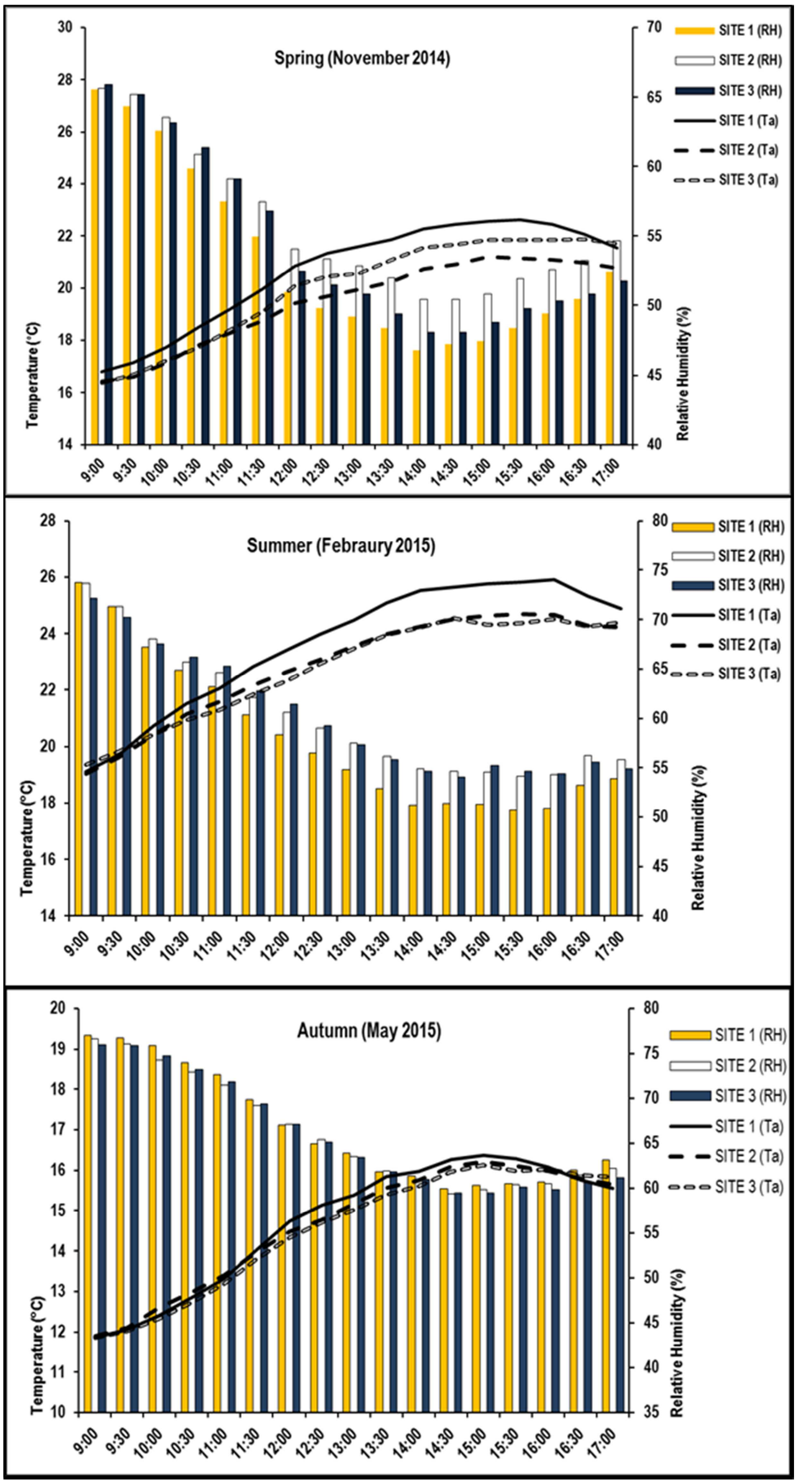


Figure 6.4. The seasonal variation pattern of Ta and RH in the study sites
Source: stationary measurements

6.3.3 METEOROLOGICAL CONDITIONS OF RUCC USING THE MOBILE SYSTEM

The mobile measurement system was only used during field surveys and observations (from 9:00 am to 5:00 pm). In total 45 days of mobile measurements were conducted to portray the conditions of thermal environment at the time of survey in the three study sites. The ensuing information from this measuring system was later employed to understand human-place interaction under different climate conditions. A portable mini weather station was used to concurrently monitor the four environmental variables (T_a, RH, V_a and T_g) with questionnaire surveys (36 days) and unobtrusive observations (12 days). The detailed specification of devices used in the mobile measurement system is provided in Chapter 4. Table 6.4 presents the results of microclimate evaluation in study sites. As tabulated below, conditions of microclimate in spring and summer largely varied compared to that in autumn. For instance, compared to summer the mean T_a and T_g in autumn was lower which are 8.6 ˚C and 12.3 ˚C, respectively.

The results pointed to a consistency in measurements produced by the weather station and BOM station (Table 6.2). In spring, the largest values for SR (486 $W.s^{-2}$) and T_g (27.4 ˚C) were registered, indicating the existence of intense solar radiation. This finding, however, contradicted the BOM station's measurements for both the study period and the five years before in which solar radiation was greater in summer. As the measurements were concurrent to field surveys, the comparative analysis for study sites revealed that except for summer in the case of V_a and T_a, Site 3 was subject to lower temperature ($\bar{x}$= 20.2 ˚C), windier conditions ($\bar{x}$=1.8 $m.s^{-1}$), weaker solar radiation (320 $W.s^{-2}$) and more humid conditions ($\bar{x}$= 55.7%). One possible explanation could be the effect of shade on the varied environmental parameters in this site, where surrounding high-rise buildings excessively casted shade on the ground where the weather took measurements of the variables.

Table 6.4. The summary of climate conditions across the RUCC.

Variable	Unit	Mean			Max			Min			Stdev		
		Spring	Summer	Autumn	Spring	Summer	Autumn	Spring	Summer	Autumn	Spring	Summer	Autumn
Site 1													
Ta	˚C	22.8	22.2	17.4	27.3	27.8	23.0	17.7	18.7	13.8	1.8	2.1	2.4
RH	%	39.2	55.6	49.0	61.5	72.5	62.0	29.1	40.1	35.4	6.5	7.6	6.9
Tg	˚C	26.4	27.3	20.5	36.1	36.6	30.1	15.2	20.6	13.1	3.8	4.5	5.0
Va	$m.s^{-1}$	1.4	1.9	1.1	3.4	3.9	4.3	0.4	0.4	0.0	0.6	0.6	0.6
SR	$W.s^{-2}$	644	502	174	1137	996	636	25	59	17	348	314	155
Site 2													
Ta	˚C	23.8	29.1	16.7	36.1	34.5	23.2	14.9	23.0	12.1	6.1	3	2.2
RH	%	34.2	48.4	50.5	53.0	72.5	66.0	17.9	28.1	39.4	11.0	13	6.2
Tg	˚C	28.7	34.6	18.2	46	45.7	30.6	16	25.1	12.5	7.3	4.5	3.2
Va	$m.s^{-1}$	1.6	1.5	1.2	4.0	3.4	3.0	0.5	0.2	0.4	0.6	0.7	0.5
SR	$W.s^{-2}$	443	517	129	1067	948	552	28	26	4.70	357	324	144
Site 3													
Ta	˚C	19.3	24.3	15.1	26.3	29.1	17.6	14.3	19.5	12.6	2.4	2.4	1.4
RH	%	49.0	60.3	58.4	74.3	80.8	75.1	34.8	37.4	51.1	7.1	9.8	4.9
Tg	˚C	23.6	27.4	15.8	35.4	40.5	18.6	15.4	20.7	13	5.1	4.7	1.3
Va	$m.s^{-1}$	1.6	1.5	2.3	4.1	4.6	6.2	0.5	0.2	0.6	0.6	0.7	1.3
SR	$W.s^{-2}$	486	352	129	1076	921	167	42	13	11	343	334	36
Combined													
Ta	˚C	22.0	25.2	16.6	33.9	34.5	23.3	14.71	18.6	12.1	4.5	3.9	2.1
RH	%	49.0	54.6	53.1	74.3	80.8	75.2	18	28.2	35.4	10.7	11.4	7.5
Tg	˚C	24.5	29.8	17.5	44.5	45.7	30.6	15.8	20.6	12.6	6	5.7	3.6
Va	$m.s^{-1}$	1.6	1.5	1.6	4.1	4.6	6.3	0.5	0.2	0.3	0.6	0.7	1.1
SR	$W.s^{-2}$	516	461	122	1137	996	636	25.6	13.1	4.7	359	331	131

Source: mobile measurements

6.4 THERMAL CONDITIONS OF GROUND COVER MATERIALS

Air temperature near to ground surfaces otherwise known as surface temperature (T_S) is one of the determinants of outdoor thermal environment particularly in dense urbanised areas where various surfaces are commonly included in designs. The study sites included a number of surfaces featuring varied thermal behaviours. Surface temperature sensors were set up to measure the seasonal and diurnal thermal behaviour of surface material at the study sites from 10:00 am to 5:00 pm. The measurements allowed for comparative eluviation of T_S between surface materials to capture their thermal behaviour in various seasons. In each site, the diurnal and seasonal T_S of four dominant materials were monitored and compared. The specifications of these materials are presented in Chapter 5 under the three study sites.

Figures 6.5 to 6.7 illustrate the pattern of diurnal change in thermal conditions of various surfaces in each study. In Site 1, in general two surfaces revealed higher temperature values during the hours of field study; these included "garden bed with 5 cm of woodchips" (x̄=30.4 ˚C, σ= 2.5 ˚C) and "Astroturf" (x̄=29.2 ˚C, σ= 2.5 ˚C), with a significant difference from "timber deck" (x̄=24.1˚C, σ= 2.5 ˚C). The diurnal variation of T_s also indicated that the surfaces experienced the hottest conditions between 14:00 and 15:00 for all seasons in Site 1. These patterns of T_s diurnal change demonstrated no noticeable distinct variance among the study surfaces and they followed more or less a similar pattern.

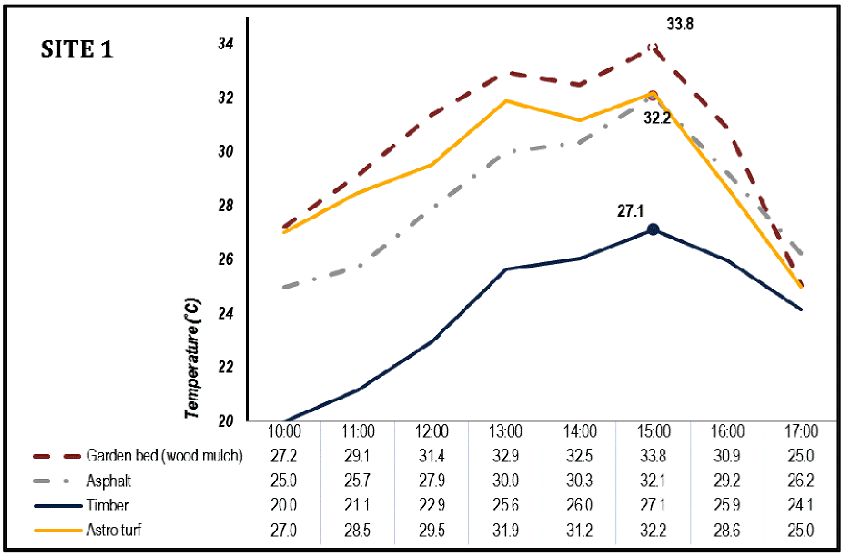
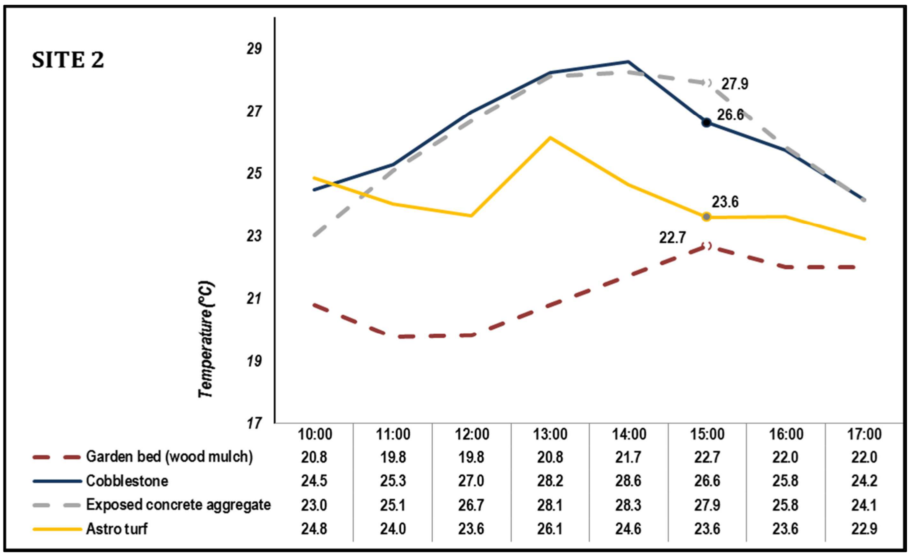


Figure 6.5. Thermal behaviour of various surfaces in Site 1

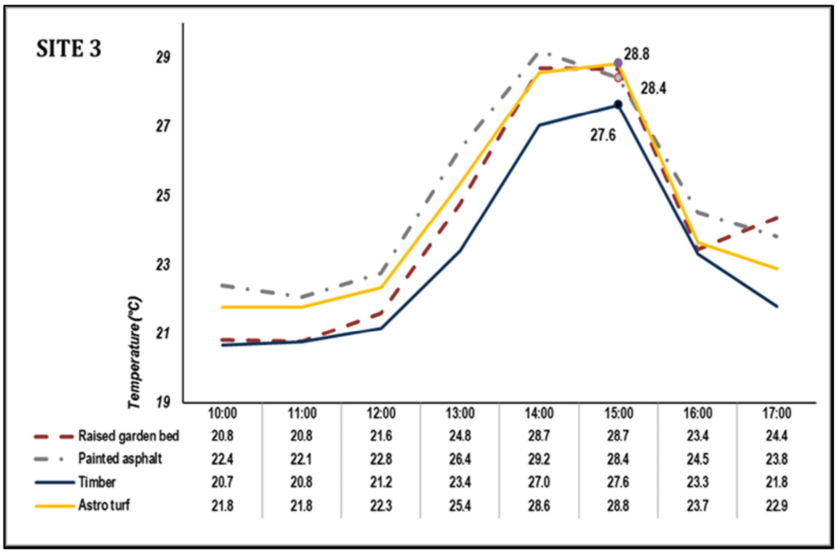
In Site 2, the T_s of four surfaces were monitored and compared, between which "cobblestone" and "exposed concrete aggregate" with respectively averages of 26.3 ˚C and 26.1˚C, exhibited higher thermal mass. Unlike findings in Site 1, the measurements in Site 2 demonstrated lower values of T_s in "garden bed" (x̄=21.2 ˚C) and "Astroturf" (x̄=24.2 ˚C). The occurrence of lower T_s in these two sites could relate to varied irrigation planning, where as opposed to plants in Site 1 these beds in Site 2 were more frequently irrigated. Furthermore, lower thermal fluctuation was registered for "Astroturf" (σ= 0.97 ˚C) and "garden bed" (σ=1.05 ˚C) in comparison to exposed concrete aggregate (σ= 1.5 ˚C). The peak of T_s occurred within a wider range of 12:00 pm and 15:00 pm. Figure 6.6 depicts the thermal behaviour of the study materials in Site 2.



	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
Garden bed (wood mulch)	20.8	19.8	19.8	20.8	21.7	22.7	22.0	22.0
Cobblestone	24.5	25.3	27.0	28.2	28.6	26.6	25.8	24.2
Exposed concrete aggregate	23.0	25.1	26.7	28.1	28.3	27.9	25.8	24.1
Astro turf	24.8	24.0	23.6	26.1	24.6	23.6	23.6	22.9

Figure 6.6. Thermal behaviour of various surfaces in Site 2

At Site 3 among the study surface materials, "timber" had the lowest T_s throughout the study period ($\bar{x}$=23.2 ˚C), followed by the "garden bed" ($\bar{x}$=24.1 ˚C). The lowest value of T_s in timber deck was also found in Site 1. However, the pattern of change in T_s was rather similar among the surfaces in Site 3. The peak of T_s in study surfaces occurred between 14: pm and 15:00 pm. Figure 6.7 presents the variation in thermal behaviour of the surfaces in Site 3.



	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
Raised garden bed	20.8	20.8	21.6	24.8	28.7	28.7	23.4	24.4
Painted asphalt	22.4	22.1	22.8	26.4	29.2	28.4	24.5	23.8
Timber	20.7	20.8	21.2	23.4	27.0	27.6	23.3	21.8
Astro turf	21.8	21.8	22.3	25.4	28.6	28.8	23.7	22.9

Figure 6.7. Thermal behaviour of various surfaces in Site 2

6.4.1 SURFACE TEMPERATURE UNDER SUNNY AND SHADED CONDITIONS

The extent of sunlight or shade on ground covering materials dictates their thermal conditions in urban spaces. Shadow pattern per se is determined by geometry of a space, time of the year, and surrounding obstacles represented by SVF and aspect ratio. To understand the effect of shading on thermal behaviour of study surface materials the T_s of materials, being exposed to sun and shade under different light conditions, were investigated and compared for Sites 1 and 3 in February 2015. For Site 1, the measurements of some sections of two days (12.02.2015 and 24.02.2015) on thermal behaviour of "garden bed", "asphalt", "AstroTurf", and "timber deck" served to investigate such an effect. These time periods were selected as the surfaces were simultaneously under shade or sun exposure. As depicted in Figure 6.8, the results showed that Astroturf under direct sun exposure had larger T_s than asphalt throughout the measuring period, whereas under the shade conditions its temperature fell below that of asphalt in some points in time. This finding means that the level of access to solar radiation is decisive in thermal behaviour of ground surfaces in cities.

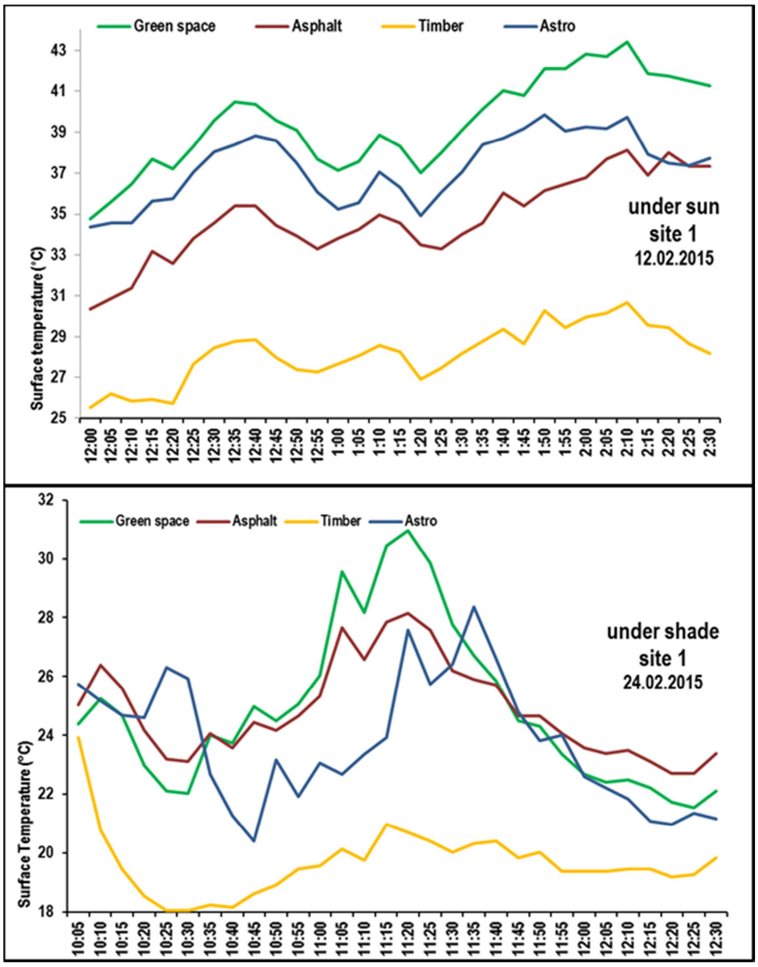


Figure 6.8. Surface temperature of different surfaces under shade (below) and sun (top) in Site 1

In Site 3, only one day (27.02.2015) was selected to examine thermal behaviour of the four surfaces in different light conditions: sunny conditions (10:10 am to 12:00 pm) and shaded conditions (12:30 to 14:10 pm). In the sunny position, "raised garden bed" and "Astroturf" were found to have the largest T_S, followed by "painted asphalt" and "timber deck". However, under shade in general the opposite was observed where the painted asphalt had the lowest decrease in T_S, whereas this value in raised garden bed and Astroturf had constant downward trends (Figure 6.9). From the findings at these two sites, it seems that under any sunny conditions, timber deck had the coolest T_S and the pattern of T_S variation of garden beds and Astroturf changed with light conditions.

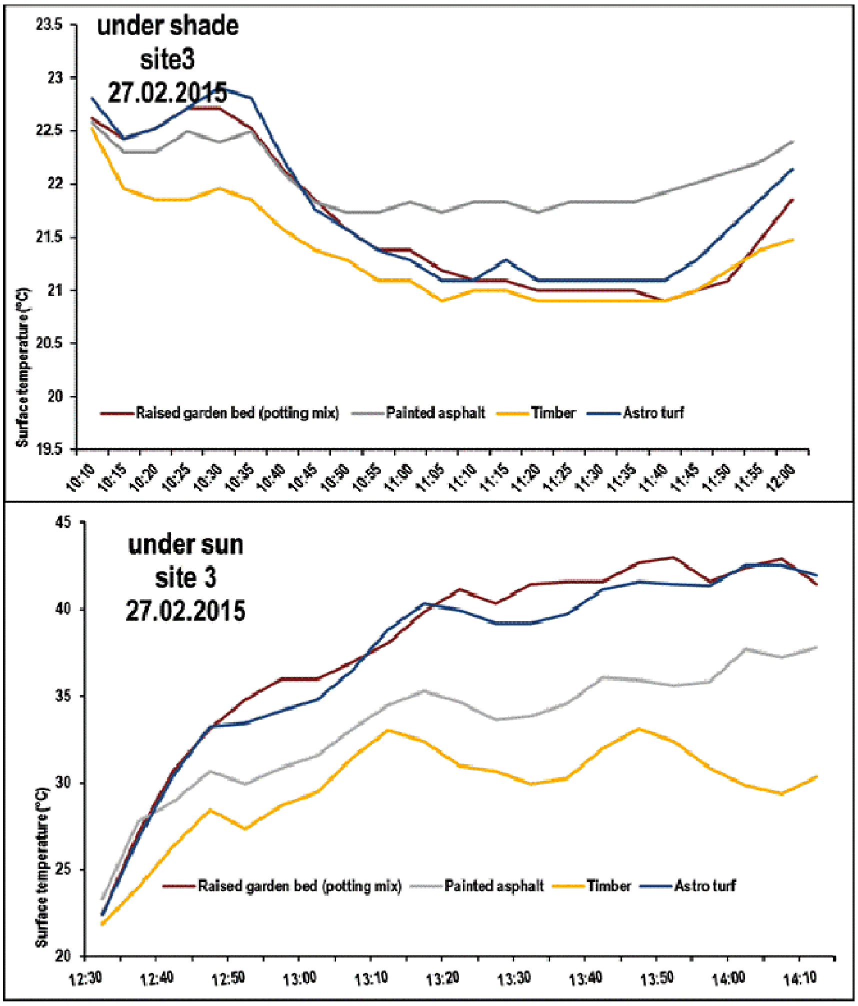


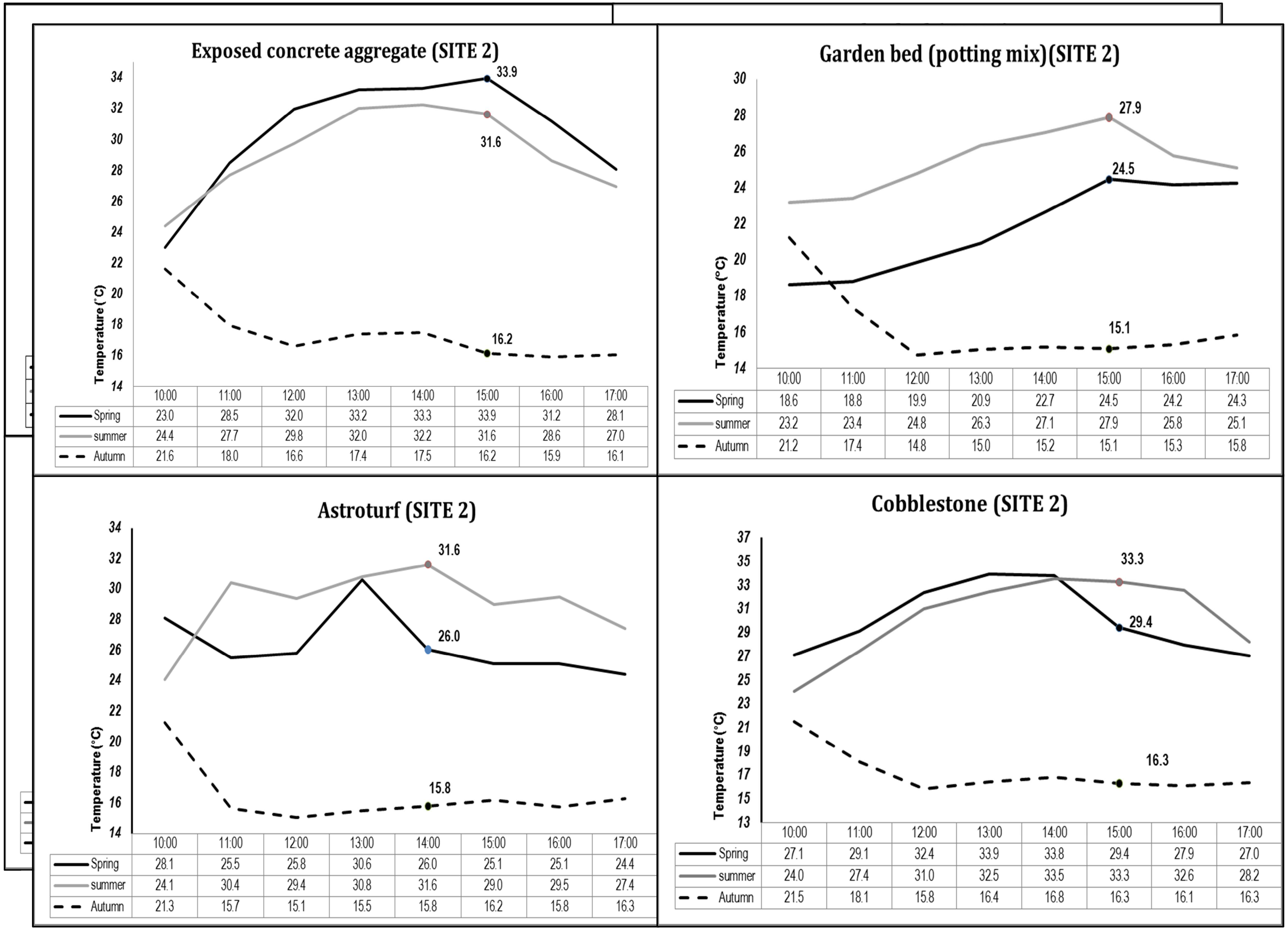
Figure 6.9. Surface temperature of different surfaces under shade (below) and sun (top) in Site 3

6.4.2 SEASONAL THERMAL CONDITIONS OF SURFACES

Thermal conditions of surface materials change with climate conditions and they are largely subject to varying amounts of solar radiation in different seasons. To track down changes in the thermal behaviour of surfaces, the measurements from each season were contrasted against the hours of study. Figures 6.10 to 6.12 illustrate the

T_s variation trends in study surfaces in different seasons. In Site 1, higher temperature values were recorded in spring (Figure 6.10), when strong solar radiation arrived at the surfaces (Table 6.2). There was a significant drop in T_s from spring to autumn when the sky became cloudier and the surfaces' exposure to direct solar radiation was limited. The results revealed that this drop in "garden bed" was 18.3 °C, and for asphalt and timber deck respectively, it was 16.1 °C and 10.1 °C.

In Site 2, all the surface materials also had significantly lower temperature in autumn, relative to the other two seasons (Figure 6.11). The largest seasonal drop occurred in the hard surfaces, with 17°C and 17.7°C for "cobblestone" and "exposed concrete aggregate", respectively. The lowest thermal variation in this site was found to belong to garden bed when its T_s only decreased from 12.8 °C from summer to autumn. Interestingly the higher T_s values in "cobblestone" was measured in spring and this finding contradicts measurements of the other surfaces at this site. Like other sites, there was a noticeable drop in T_s at Site 3 from summer to autumn (Figure 6.11). Among the surfaces, "garden bed" and "painted asphalt" had the lowest thermal fluctuation from spring to autumn. The results also recorded that there was a sharp rise in T_s in summer afternoon (14:00 to 15:00 pm) at Site 3, revealing the interaction between seasons and surface temperature in urban spaces. In general, the fluctuations in the study cold season were considerably lower than the other seasons.



Exposed concrete aggregate (SITE 2)

	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
Spring	23.0	28.5	32.0	33.2	33.3	33.9	31.2	28.1
summer	24.4	27.7	29.8	32.0	32.2	31.6	28.6	27.0
Autumn	21.6	18.0	16.6	17.4	17.5	16.2	15.9	16.1

Garden bed (potting mix)(SITE 2)

	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
Spring	18.6	18.8	19.9	20.9	22.7	24.5	24.2	24.3
summer	23.2	23.4	24.8	26.3	27.1	27.9	25.8	25.1
Autumn	21.2	17.4	14.8	15.0	15.2	15.1	15.3	15.8

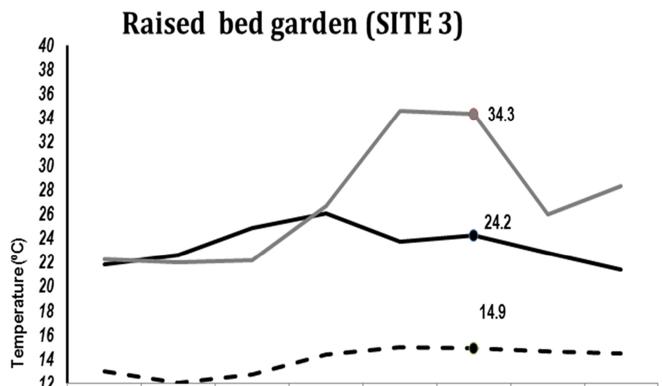
Astroturf (SITE 2)

	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
Spring	28.1	25.5	25.8	30.6	26.0	25.1	25.1	24.4
summer	24.1	30.4	29.4	30.8	31.6	29.0	29.5	27.4
Autumn	21.3	15.7	15.1	15.5	15.8	16.2	15.8	16.3

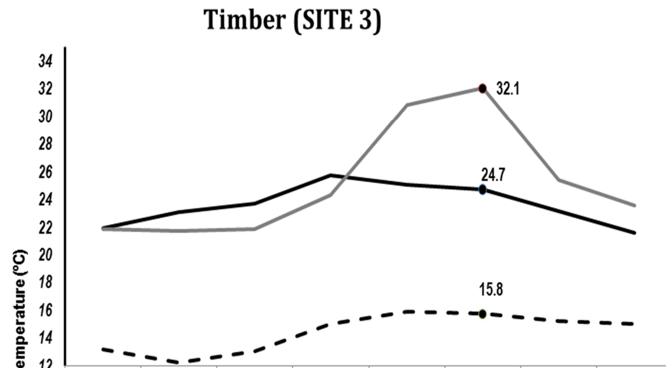
Cobblestone (SITE 2)

	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
Spring	27.1	29.1	32.4	33.9	33.8	29.4	27.9	27.0
summer	24.0	27.4	31.0	32.5	33.5	33.3	32.6	28.2
Autumn	21.5	18.1	15.8	16.4	16.8	16.3	16.1	16.3

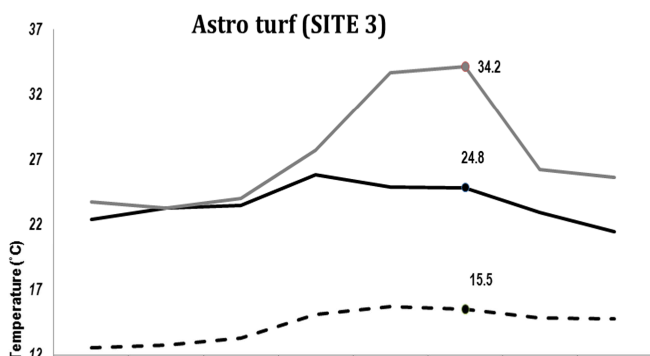
Figure 6.11. Seasonal change in surface temperature in Site 2



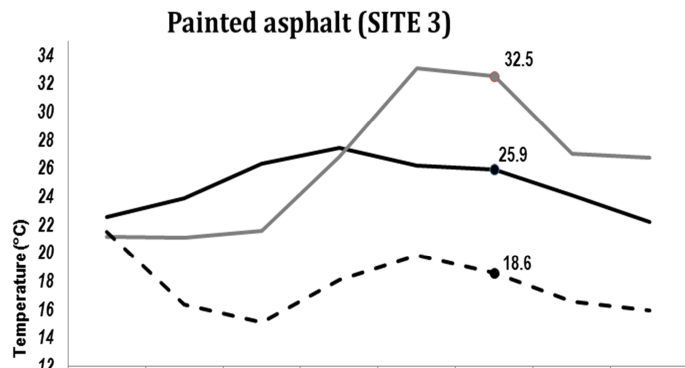
	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
spring	21.8	22.6	24.8	26.0	23.8	24.2	22.8	21.4
summer	22.3	22.0	22.2	26.7	34.6	34.3	26.0	28.3
autumn	13.0	12.1	12.7	14.4	14.9	14.9	14.6	14.4



	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
spring	21.9	23.1	23.7	25.7	25.1	24.7	23.2	21.6
summer	21.9	21.7	21.9	24.3	30.8	32.1	25.4	23.6
autumn	13.2	12.2	13.1	15.0	15.9	15.8	15.2	15.0



	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
spring	22.4	23.3	23.5	25.8	24.9	24.8	23.0	21.4
summer	23.8	23.3	24.0	27.7	33.7	34.2	26.2	25.6
autumn	12.5	12.8	13.3	15.1	15.7	15.5	14.8	14.8



	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
spring	22.6	23.9	26.3	27.5	26.2	25.9	24.1	22.2
summer	21.2	21.1	21.6	26.8	33.1	32.5	27.0	26.8
autumn	21.5	16.4	15.1	18.1	19.9	18.6	16.6	16.0

Figure 6.12. Seasonal change in surface temperature in Site 3

6.5 URBAN DESIGN CHARACTERISTICS OF THE STUDY SITES

To understand the interaction between urban design and environmental variables the effect of a descriptor of design, SVF, on climate conditions was assessed. As stated before, SVF indicates the proportion of the sky that is not an obstacle and whereby sunlight can come through. This design descriptor was calculated for each site and the results are presented in Chapter 5. As tabulated in Table 6.5, it is evident that generally there were strong associations between SVF and environmental variables. However, season-wise analysis showed that the level of correlations varied in different seasons. Among the variables, RH was found to have the largest correlation with SVF ($P<0.01$, $r= 0.24$) throughout the study period; yet others had varying correlations in different seasons. For instance, the results for the relationship between the values of variables and SVF suggested the greatest correlation coefficient for SR and V_a in autumn, T_g and T_a in summer, and RH in spring.

Table 6.5. Results of correlation between SVF and the environmental parameters

Season	T_a	T_g	RH	V_a	SR
Spring	.33**	.05 ns	-.27**	-.23**	.03*
Summer	.48**	.40**	-.20**	-.17**	.10*
Autumn	.20**	.28**	-.20**	-.26**	.18**
Pooled	.16**	.15**	-.24**	-.17**	.13**

Note: level of significance: ** significant at the 0.01 level, *significant at the 0.05 level, ns: non- significant

6.6 LEVEL OF ACTIVITY (METABOLIC RATE) AND CLOTHING INSULATION

Two personal thermal factors –clothing insulation and level of activity - were assessed using the information obtained from supplementary observation and questionnaire survey. As these two factors directly influence the human body's thermoregulation system, the ensuing findings indicate the conditions in which participants judged their immediate thermal environment. Table 6.6 provides the characteristics of these two personal thermal factors across the study seasons and sites. Findings were representative of a shift in the way users dressed in different seasons ranging from moderately light (spring) to light (summer) and heavy (autumn); the averaged clothing insulation (Clo) doubled from summer (0.41) to autumn (0.81).

Table 6.6. Personal thermal factors across the study seasons.

Personal thermal factors	*Combined*	*Spring*	*Summer*	*Autumn*
	N=1053	N=368	N=407	N=278
Clothing insulation (*Clo*)				
Average	0.56	0.55	0.41	0.81
Std. dev	0.009	0.02	0.01	0.01
Max	1.31	1.10	1.15	1.31
Min	0.06	0.06	0.16	0.25
Level of activity (*met*)				
Average	1.46 (84.97 w/m^2)	1.41 (82.06 w/m^2)	1.40 (81.20 w/m)	1.45 (84.39 w/m^2)
Std. dev	0.77	0.78	0.79	0.80
Min	0.80	0.80	0.80	0.80
Max	3.40	3.40	3.40	3.40
	SITE 1	**SITE 2**	**SITE 3**	
	N=347	**N=365**	**N=339**	
	1.28	1.33	1.66	
Average	0.68	0.69	0.92	
Std. dev	0.80	0.80	0.80	
Min	3.40	3.40	3.40	
Max				

The level of activity was found to be independent of seasonal change where the activity level (met) was roughly constant over the study seasons (Table 6.6). However, the participants had slightly different activity levels in different sites, where compared to sites 1 (1.28 met) and 2 (1.33 met) visitors of Site 3 had relatively more activity (1.66 met). This difference is attributed to the facilities such as basketball courts, table tennis and jogging lanes providing opportunities for visitors to do physical activities.

Level of clothing insulation and activity was also compared between genders; the results suggested varying patterns between males and females (Table 6.7). In the case of clothing, compared to the males ($\bar{x}$=0.54 Clo), females tended to wear slightly heavier garments ($\bar{x}$= 0.60 Clo). This difference was, however, more evident in spring when the results showed a 0.16 Clo difference. In summer, both genders had a relatively similar range of clothing, between 0.16 Clo and 1.15 Clo. The difference in the level of activity was suggestive of higher levels for male participants (Table 6.7). On average, males had an activity level of 1.49 *met* which was 18.2% more than their female counterparts with a level of 1.26 *met*. This imbalance in the level of activity remained steady in all seasons and reached 26.6% at its peak in spring.

Table 6.7. Summary of clothing and activity level in genders three seasons and overall.

Personal thermal factors	Combined		Spring		Summer		Autumn	
	N=1053		N=368		N=407		N=278	
	Male	Female	Male	Female	Male	Female	Male	Female
Clothing insulation (Clo)								
Average	0.54	0.60	0.50	0.64	0.39	0.45	0.79	0.86
Std. dev	0.29	0.30	0.27	0.29	0.20	0.25	0.25	0.21
Min	0.06	0.16	0.60	0.19	0.21	0.16	0.26	0.26
Max	1.31	1.15	1.10	1.08	1.15	1.10	1.31	1.15
Level of activity (*met*)								
Average	1.49	1.26	1.52	1.20	1.46	1.29	1.49	1.32
Std. dev	0.83	0.68	0.84	0.62	0.83	0.72	0.83	0.72
Min	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Max	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40

6.7 CALCULATED THERMAL COMFORT INDICES

Following establishing trends of variations in environmental parameters that formed the surrounding thermal environment of people in the survey, this section presents the calculations of comfort indices. The calculations considered the values of four environmental parameters and two personal factors and predicted comfort conditions. Three comfort indices of PET, UTCI and OUT-SET* served to predict comfort conditions in RUCC. The calculation procedure for each index is presented in Chapter 4. The predictions show the comfort level in different seasons over the entire period of study and where relevant for the study sites. To understand the thermal behaviour of comfort indices, the index values were compared to corresponding T_a and T_{mrt}; the results are shown in Figure 6.13. In general, the trends revealed the pattern of variation in index values resembled that of T_a. However, within a particular range (12 °C to 26 °C), the indices produced lower temperature compared to T_a.

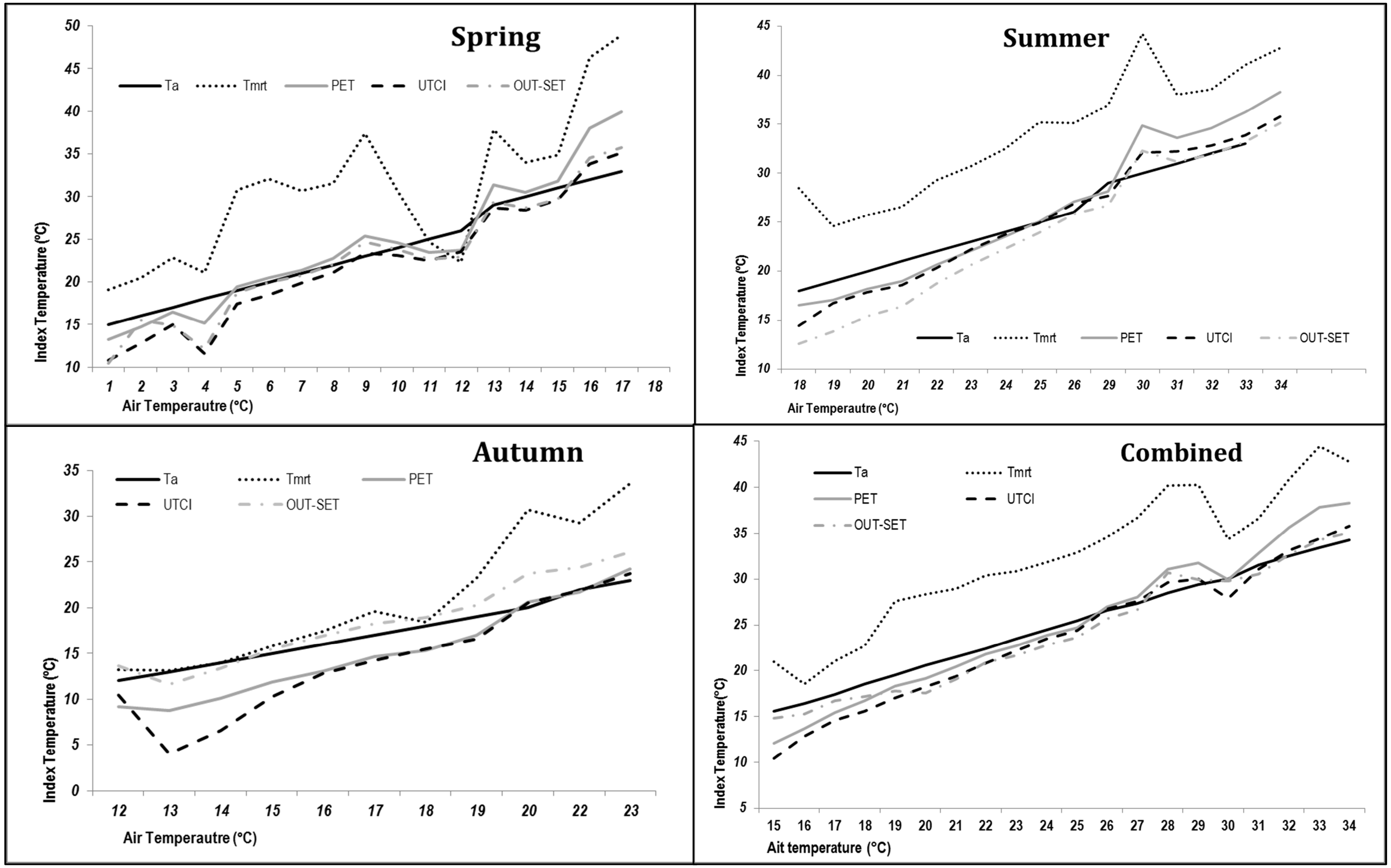


Figure 6.13. Overall and seasonal thermal behaviour of comfort indices

Table 6.8 comprises the summary statistics of thermal behaviour of comfort indices. Among the indicators of thermal conditions, it seems that T_{mrt} estimated higher values almost in every situation. This difference in indication of thermal condition in T_{mrt} relates to its calculation protocol in which RH is not considered. As shown in the table below, in comparison to the two other indices, OUT-SET respectively overestimated thermal conditions in autumn (Δ>3.6 ˚C), and underestimated in summer (Δ>1.4 ˚C).

Table 6.8. Summary statistics on calculated thermal comfort conditions.

	Spring	Summer	Autumn	Combined
	N=368	N=413	N=247	N=1023
		Ta		
Average	22.05	25.2	16.6	22
Stdev	4.05	3.9	2.1	5
Max	33.9	34.5	23.3	34.5
Min	14.7	18.8	12.1	12.1
		T_{mrt}		
Average	29.7	32.8	18	28.2
Stdev	7.6	7.2	34.2	9
Max	50.9	51	12	51
Min	9.7	21.2	4.7	9.7
		PET		
Average	21.9	24.8	13.4	21
Stdev	5.89	5.9	3.2	7
Max	40.7	42.1	24.7	42.1
Min	11.2	14.9	7.4	7.4
		UTCI		
Average	20	24.3	12.2	19.9
Stdev	5.7	5.49	5.5	7.2
Max	35.9	37.9	24.3	37.9
Min	6.6	11.1	-3.6	-3.5
		OUT-SET*		
Average	20.7	22.9	16.9	20.6
Stdev	5.7	6.2	3.3	5.9
Max	36.3	38.1	9.9	38.1
Min	6.6	9.5	26.2	6.6

Thermal conditions and comfort predictions of study sites were compared to establish thermal environment of survey participants in different seasons. As presented in Table 6.9, the results showed that in general, Sites 2 and 3 experienced respectively the greatest and lowest temperature values during the field surveys. Comparing the standard deviation of aggregated data, results showed that thermal fluctuations occurred more in Site 1 than the two other sites. By-season analysis suggested the same trend in thermal conditions for the study sites during spring and summer. In autumn, however, higher temperature values occurred in Site 1 followed by Site 2; in this season, the largest standard deviation belonged to temperature values experienced in Site 1.

Table 6.9. Summary statistics on calculated thermal comfort in three sites.

	Spring			Summer			Autumn			Combined		
Site:	1	2	3	1	2	3	1	2	3	1	2	3
N:	108	139	121	148	139	126	59	88	95	315	366	342
T_a												
Average	22.8	23.8	19.4	22.2	29.1	24.3	17.6	16.7	15.8	21.5	24.1	20.2
Stdev	1.9	6	2.4	2.1	3	2.4	2.4	2.3	1.3	2.8	6.4	4
Max	29.4	34	24.8	27.3	34.5	29.1	23	23.3	18.6	27.4	34.5	29.1
Min	17.7	15.8	14.7	18.7	23	19.5	13.9	12.1	13	13.9	12.1	13
T_{mrt}												
Average	28.7	32	28	30.9	37.9	29.4	21.5	19	15	28.4	31.2	24.9
Stdev	6.5	8	7.4	6.4	5.8	6.5	5.3	4	2.9	7.1	9.7	8.6
Max	40.8	50.9	44.4	43.8	51	47	32.9	34.2	30.2	43.8	51	47
Min	10	18	16.1	21.2	26	21.5	15.9	12.9	12	9.73	12.9	12
PET												
Average	22.2	24	19.3	21	30.5	23	15.6	14	11.4	20.4	24	18.5
Stdev	2.5	7.9	3.9	3.6	4.9	4.1	3.6	2.9	2.11	4	8.7	5.9
Max	29.3	40.7	27	30.4	42.1	34.1	23.7	24.7	15.6	30.4	42.1	34.1
Min	17.2	12.8	11	14.9	20.6	16.4	10.8	7.7	7.4	10.8	7.7	7.4
UTCI												
Average	20.8	21.7	17.5	20.3	29.4	23.3	15.8	14.2	8.1	19.6	22.8	17
Stdev	2.7	7.5	4.1	4	3.9	3.9	3.7	3.4	5.5	4	8	7.5
Max	26.5	35.9	25.2	29.8	37.9	30.7	23.2	24.3	16.8	28.8	37.9	30.7
Min	14	7.8	6.6	11.1	20.3	15.8	8.8	5.2	-3.6	8.8	5.2	-3.6
OUT-SET*												
Average	21.4	22.4	17.9	19.9	28.6	21.4	19.1	17.5	14.6	19.8	23.6	18.3
Stdev	2.6	7.4	4.6	5	4.3	4.7	3.3	2.7	2.4	4.2	7	5
Max	27.8	36.3	25.9	42.2	38	31.5	25.9	26.8	19.3	42.2	38	31.5
Min	15.3	9.6	7.5	9.5	18.4	12.9	14.2	11	10	9.4	9.6	7.5

Furthermore, the strength of the relationship between these indices and variables contributed to their calculations (environmental parameters and personal factors) being investigated for different seasons. This link was also established for solar intensity (SR), despite the fact it was not accounted for directly in computations of these indices. Table 6.10 shows the results of Pearson's correlation test carried out to evaluate their seasonal interrelationships. As shown below, from all the variables, T_a with correlation coefficients above 0.89 and the level of activity with less than 0.13 were found to have, respectively, the strongest and weakest correlations with the indices. Accordingly, the most effective factors in the prediction of thermal comfort were found to be in the descending order of T_a, T_g (T_{mrt}), RH, V_a, Clo and met.

The relationships between indices and the variables were generally consistent, however, the strength of these relationships varied according to the season, particularly in the cases of RH, V_a, SR and two personal factors. For instance, V_a had noticeably stronger relationships with indices in autumn than other seasons. In the case of clothing the correlation results, using aggregated data were indicative of a strong relationship with the indices. Yet seasonal data showed considerably weaker strength in such relationships.

Table 6.10. Summary of correlation between the thermal indices and climate variables.

Dependent variable	Time	Ta	T_{mrt}	RH	V_a	T_g	SR	Clo	met
PET	Combined	0.96**	0.88**	-0.51**	-0.25**	0.95**	0.51**	0.42**	-0.10**
	Spring	0.93**	0.77**	0.82**	-0.26**	0.91**	0.28**	-.22**	0.00^{ns}
	Summer	0.95**	0.82**	-0.71**	-0.37**	0.93**	0.39**	-0.08 ^{ns}	-0.12*
	Autumn	0.92**	0.91**	-0.67**	-0.55**	0.94**	0.68**	-0.07^{ns}	-0.30**
UTCI	Combined	0.93**	0.81**	-0.41**	-0.43**	0.90**	0.44**	-0.42**	-0.13**
	spring	0.93**	0.68**	-0.81**	-0.41**	0.85**	0.23**	-0.22	-0.008^{ns}
	Summer	0.95**	0.73**	-.64**	-0.50**	0.87**	0.31**	-0.11*	-0.10*
	Autumn	0.70**	0.74**	-0.49**	-0.87**	0.75**	0.46**	0.03^{ns}	-0.36**
OUT-SET	Combined	0.89**	0.81**	-0.55**	-.34**	0.89**	0.47**	-0.32**	-.11**
	Spring	0.92**	0.78**	-0.82**	-0.25**	0.92**	0.32**	-0.21**	-0.02^{ns}
	Summer	0.94**	0.82**	-.68**	-0.40**	0.93**	0.42**	-.11*	-0.11*
	Autumn	0.86**	0.87**	-0.62**	-0.67**	0.89**	0.61**	-0.05	-0.33**

****Significant at 0.01 level, * significant at 0.05 level, ns: non-significant**

6.8 THERMAL RESPONSES BY PARTICIPANTS

The participants voted for their thermal perceptions on their immediate thermal environment using various scales provided to them at the time of field surveys. These included: thermal sensation votes on seven-point ASHRAE scale (TSV), thermal acceptance on binomial basis (acceptable vs. not acceptable), thermal preference on three-point McIntyre scale (cooler, no change, warmer) and overall comfort on a seven-point scale. Furthermore, based on analyses of information derived from thermal scales mentioned above, users' thermal neutrality, preferred temperature, and acceptable thermal ranges were determined. Accordingly, the analytical findings on thermal responses are reported for the data obtained during the entire period of study, each study season, and site.

6.8.1 THERMAL SENSATION

The users' thermal sensations on TSV scales were acquired while the surrounding meteorological conditions were registered via a mobile measurement system. The profile of TSVs in different seasons and for the entire period of study in different sites is presented in Table 6.11 and Figure 6.14. The differences in TSVs in varying seasons indicated the role of seasonal change on the development of people's actual thermal sensations. The mean TSV for spring, summer and autumn was found to be 0.50, 0.78 and -1.47, respectively. As indicated by Nikolopoulou et al. (2001) and Spagnolo and de Dear (2003) the observed difference in the distribution of thermal responses between seasons is partially explained by a bias for warm temperature values in cold seasons.

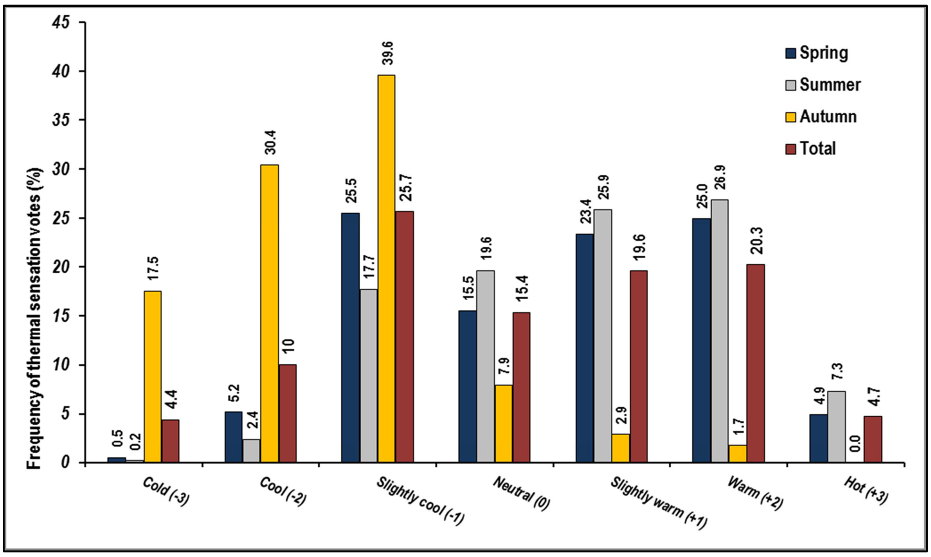


Figure 6.14. Frequency distribution of thermal sensation votes in different seasons.

According to indoor thermal comfort standards (ISO 7730 2006) three categories are assumed to represent the achievement of comfort or thermal satisfaction with the immediate thermal environment. The distribution of combined votes suggests that the majority of users in this study (60% of total outdoor users) perceived thermal conditions somewhere between "slightly cool" (25.7%), "neutral" (15.4%), and "slightly warm" (19.6%). By-season analysis illustrated a shift in votes from the warm side of the scale (+1 to +3) in spring and summer to the cool side (-1 to -3) in autumn (Figure 7.14). As expected, spring with more than 64% of votes cast on three central categories, had the first rank in comfort conditions, closely followed by that in summer (63.2%). However, the TSV distribution in autumn was different due to a noticeable drop in T_a (Table 6.9) and votes were biased towards the cooler sides of scale; in effect only around 50% of total users voted for central categories.

As tabulated in Table 6.11, in general, among the study sites, Site 2 with mean TSV of 0.48 was perceived to be warmer than other two sites with 0.17 (Site 1) and -0.21 (Site 3) mean TSV, respectively. However, by-season analysis showed that in spring thermal conditions were comparatively perceived to be warmer (0.88) than in the other sites. In summer, mean TSV in Site 2 (1.56) had a large difference with that in Site 1 (0.25) and Site 3 (0.54); this pattern corresponds to warmer thermal conditions registered in Site 2 (Table 6.9). In autumn, people in Site 3 perceived thermal conditions to be cooler (-1.81) than other sites with -1.36 (Site 1) and -1.18 (Site 2); a similar trend was observed in spring and summer. In terms of votes in the three central categories, in general, the results showed a higher percentage in Site 3 (62.3%). This trend referred to higher frequency of thermal votes cast within central categories of warmth scale during spring and particularly in summer. As indicated in Table 6.9, during warm seasons, visitors to Site 3 experienced rather cooler conditions. Among the study sites, more people in Site 2 (57.7%) voted for the category of slightly cool to slightly warm.

Table 6.11. Summary of participants' thermal sensation in different seasons and sites.

				Cold (-3)		Cool (-2)		Sli. cool (-1)		Neutral (0)		Sli. warm (1)		Warm (2)		Hot (3)	
		Mean	Std dev	No	%	No	%	No	%	No	%	No	%	No	%	No	%
Spring	aggregated	0.5	1.39	2	0.5	19	5.2	94	25.5	57	15.5	86	23.4	92	25	18	4.9
	Site1	0.88	1.22	0	0	2	1.9	20	18.5	12	11.1	33	30.6	37	34.3	4	3.7
	Site2	0.45	1.45	2	1.4	6	4.3	40	28.8	20	14.4	30	21.6	32	23	9	6.5
	Site3	0.23	1.38	0	0	11	9.1	34	28.1	25	20.7	23	19	23	19	5	4.1
Summer	aggregated	0.78	1.29	1	0.2	10	2.4	73	17.7	81	19.6	107	25.9	111	26.9	30	7.3
	Site1	0.25	1.24	1	0.7	8	5.4	40	27	31	20.9	40	27	27	18.2	1	0.7
	Site2	1.56	0.96	0	0	0	0	3	2.2	18	12.9	36	25.9	62	44.6	20	14.4
	Site3	0.54	0.54	0	0	2	1.6	30	23.8	32	25.4	31	24.6	22	17.5	9	7.1
Autumn	aggregated	-1.47	1.06	42	17.5	73	30.4	95	39.6	19	7.9	7	2.9	4	1.7	0	0
	Site1	-1.36	0.94	6	10.2	18	30.5	29	49.2	4	6.8	1	1.7	1	1.7	0	0
	Site2	-1.18	1.15	9	10.2	26	29.5	36	40.9	9	10.2	5	5.7	3	3.4	0	0
	Site3	-1.81	0.97	27	29	29	31.2	30	32.3	6	6.5	1	1.1	0	0	0	0
Combined	aggregated	0.15	1.56	45	4.4	102	10	262	25.7	157	15.4	200	19.6	207	20.3	48	4.7
	Site1	0.17	1.42	7	2.2	28	8.9	89	28.3	47	14.9	74	23.5	65	20.6	5	1.6
	Site2	0.48	1.60	11	3	32	8.7	79	21.6	47	12.8	71	19.4	97	26.5	29	7.9
	Site3	-0.21	1.58	27	7.9	42	12.4	94	27.6	63	18.5	55	16.2	45	13.2	14	4.1

The validity of assessing method of thermal acceptability has been long debated in comfort literature (Brager et al. 1993, Andamon 2005, ASHRAE 55 2010). In comfort research, three assessing methods are used to understand thermal acceptability, these being built on the three thermal scales. These methods include: (1) directly through the people's direct thermal votes on the acceptability of thermal conditions; (2) indirectly through corresponding the three central categories of TSV to thermal satisfaction; and (3) through the McIntyre preference scale (McIntyre 1980) in which "no change" in current thermal conditions is considered to be satisfaction with thermal conditions.

6.8.2 THERMAL PREFERENCE

Users of RUCC were asked to indicate their preference for the current conditions of different environmental parameters on the McIntyre (1980) three-point scale (cooler/weaker, no change, warmer/stronger). Table 6.12 summarises the data regarding frequency distribution of people's preferences for various environmental parameters. In comfort research, among the categories of thermal preference, "no change" is indicative of thermal conditions that provide satisfaction for thermal recipients (de Freitas 1985, Humphreys and Hancock 2007). The responses obtained on the preference scale showed variations in people's thermal preferences with the season. In general, results suggested that in spring more people voted for "no change" in current thermal conditions compared to other seasons; these votes included 63.9% "no change" for T_a, 58.5% for T_{mrt}, 37.6% for V_a and 82.6% for RH. This finding indicates the proximity of spring thermal conditions to respondents' thermal preferences. In summer, the proportion of people who did not request change in current thermal conditions varied; the preference for no change increased in the cases of RH and V_a with average of, respectively, 58.7 and 69.7%, and increased for T_a and T_{mrt} with seasonal average of 51.5% and 52.5%, respectively.

In autumn with a sharp reduction in mean T_a, about 41% and 68% of people wanted increases in the values of T_{mrt} and T_a respectively. Furthermore, with more than 60% of preference votes on having lower wind speeds in autumn it seems that wind speed was a serious issue in autumn compared to the other seasons. In general, the lower percentage of "no change" for wind speed in spring and autumn is attributed to gusty winds blowing during field surveys with the annual average above 1.5 $m.s^{-1}$ and reaching 6 $m.s^{-1}$ in autumn (Table 6.4). Furthermore, the request for lower wind speed always formed a considerable proportion of votes during field surveys, indicating that higher V_a were rarely welcomed in Melbourne, even during a warm spring (37.6%) and summer (32.3%). According to the wind comfort criteria developed for Melbourne CBD (GWTS 2016) and different postures, wind speeds should not be greater than 3 $m.s^{-1}$ for sitting, 4 $m.s^{-1}$ standing and 5 $m.s^{-1}$ for walking individuals. These changes in people's preferences for change in their surrounding environmental parameters show how they felt when achieving thermal comfort in outdoor spaces.

The relative humidity was steadily perceived as preferable and the majority of people did not wish a change in the level of humidity. A comparative evaluation of users' preferences for humidity revealed that while current conditions were highly preferable in all seasons, there was a noticeable desire for lower (28%) and higher humidity (14%), respectively, in summer and autumn. This trend reflected users' knowledge on how humidity impacts on thermal comfort by causing sultry conditions in summer thermal conditions and ameliorating conditions in autumn thermal conditions. By-site analysis suggested the differences in people's thermal preference in various open spaces. From the aggregated data for thermal preference in the study sites, it seems that except for humidity preference, people in Site 3 had the greatest desire for change in current thermal conditions (Table 6.12). The obvious difference in thermal preferences in this site belonged to V_a and T_a in autumn when it experienced comparatively lower temperature and stronger wind speed values (Table 6.4). These two parameters also caused higher percentages of the "no change" category at this site in summer. The other two sites had rather similar percentages of votes on "no change" for different environmental parameters.

Table 6.12. Statistical summary of people's preference votes in different seasons and sites

		Thermal (T_a) preference								Thermal (T_{mrt}) preference							
				Cooler		No Change		Warmer				Weaker		No Change		Stronger	
		Mean	Std dev	No	%	No	%	No	%	Mean	Std dev	No	%	No	%	No	%
Spring	Aggr.	2.15	.65	55	15	202	55	110	30	1.73	.58	124	34.3	211	58.2	27	7.5
	Site1	2.08	.59	15	13.9	69	63.9	24	22.2	1.60	.51	43	40.6	62	58.5	1	0.9
	Site2	2.12	.67	24	17.4	74	53.6	40	29	1.75	.56	43	31.2	86	62.3	9	6.5
	Site3	2.25	.67	16	13.2	59	48.8	46	38	1.82	.66	38	32.2	63	53.4	17	14.4
Summer	Aggr.	1.75	.65	151	36.7	212	51.5	49	11.8	1.64	.59	173	42	215	52.2	24	5.8
	Site1	1.84	.70	50	33.8	72	48.6	26	17.6	1.66	.59	59	39.9	80	54.1	9	6.1
	Site2	1.60	.57	62	44.9	70	50.7	6	4.3	1.55	.56	66	47.8	67	48.6	5	3.6
	Site3	1.83	.64	39	31	70	55.6	17	13.5	1.70	.61	48	38.1	68	54	10	7.9
Autumn	Aggr.	2.66	.51	5	2.1	72	29.9	164	68	2.34	.61	18	7.9	116	50.7	95	41.5
	Site1	2.64	.51	1	1.7	19	32.2	39	66.1	2.24	.59	5	8.5	35	59.3	19	32.2
	Site2	2.56	.52	2	2.3	36	40.9	50	56.8	2.18	.65	12	13.8	47	54	28	12.2
	Site3	2.78	.44	2	2.1	17	18.1	75	79.8	2.57	.52	1	1.2	34	41	48	21
Combined	Aggr.	2.11	.71	211	20.7	486	47.6	323	31.7	1.84	.66	315	31.2	545	53.9	151	14.9
	Site1	2.07	.69	66	21	160	50.8	138	28.3	1.75	.61	107	10.6	177	56.5	29	9.3
	Site2	2.02	1	88	24.2	180	49.5	96	26.4	1.78	.63	121	12	200	55.1	42	11.6
	Site3	2.24	.71	57	16.7	146	17.6	89	40.5	1.98	.70	89	8.6	168	50.1	80	23.9
		Wind speed (V_a) preference								Air humidity (RH) preference							
				Weaker		No change		Stronger				Lower		No change		Higher	
Spring	Aggr.	1.65	.53	136	37.6	215	59.4	11	3	1.97	.41	37	10.2	299	82.6	26	7.2
	Site1	1.75	.51	30	28.3	72	67.9	4	3.8	1.94	.41	12	11.3	88	83	6	5.7
	Site2	1.67	.53	50	36.2	84	60.9	4	2.9	1.97	.43	15	10.9	112	81.2	11	8
	Site3	1.55	.54	56	47.5	59	50	3	2.5	1.99	.40	10	2.8	99	83.9	9	7.6
Summer	Aggr.	1.77	.59	133	32.3	242	58.7	37	9	1.75	.49	114	27.7	287	69.7	11	2.7
	Site1	1.75	.60	50	33.8	85	57.4	13	8.8	1.74	.50	43	29.1	101	68.2	4	2.7
	Site2	1.89	.61	34	24.6	85	61.6	19	13.8	1.70	.52	46	33.3	88	63.8	4	2.9
	Site3	1.65	.55	49	38.9	72	57.1	5	4	1.83	.44	25	19.8	98	77.8	3	2.4
Autumn	Aggr.	1.41	.25	142	60.9	87	37.4	4	1.7	2.08	.45	15	6.4	186	79.1	34	14.5
	Site1	1.42	.49	34	57.6	25	42.2	0	0	2.15	.44	2	3.4	46	78	11	18.6
	Site2	1.55	.54	41	47.1	44	50.6	2	2.3	2.02	.43	7	8	71	81.6	9	10.3
	Site3	1.26	.49	67	77	18	20.7	2	2.3	2.1	.46	6	6.7	69	77.5	14	15.7
Combined	Aggr.	1.64	.57	416	41.1	544	53.8	52	5.1	1.91	.47	167	16.5	772	76.4	72	7.1
	Site1	1.69	.56	114	36.4	182	58.1	17	5.4	1.88	.48	57	18.2	235	75.1	21	6.7
	Site2	1.72	.58	125	34.4	213	58.7	25	6.9	1.88	.48	68	18.7	271	74.7	24	6.6
	Site3	1.50	.55	177	52.7	149	44.3	10	3	1.96	.45	42	12.5	266	79.4	27	8.1

6.8.3 OVERALL COMFORT

In accordance with the ASHRAE TSV scale, the 7-point comfort scale was used to understand overall comfort of users within a thermal environment at the time of survey. In comfort research, categories from "just right" (4) to "very comfortable" (7) on the overall comfort scale are comfort votes and connote thermal acceptability (Williams 1995). As shown in Table 6.13, the aggregate comfort votes in RUCC study yielded 68% of total participants during the period of study. By-season analysis showed that spring with the mean comfort vote of 5.72 was perceived to be comfortable compared to summer and autumn when the mean thermal comfort was rated 4.42 and 4.10, respectively (Table 6.13). The results for people's overall comfort in seasons also showed a rising trend in their thermal discomfort from spring to autumn. As shown in Figure 6.15, the percentage of outdoor users voted on discomfort categories (slightly uncomfortable to very uncomfortable) noticeably grew with the average of 8.4% in spring to 31.1% in summer and 54.9% in autumn.

Table 6.13. Statistical summary of people's overall comfort votes in different seasons and sites

				very uncomfortable 1		moderately uncomfortable 2		slightly uncomfortable 3		just right 4		slightly comfortable 5		moderately comfortable 6		very comfortable 7	
		Mean	Std dev	No	%	No	%	No	%	No	%	No	%	No	%	No	%
Spring	Aggr.	5.72	1.33	0	0	4	1.1	27	7.3	51	13.9	38	10.3	111	30.2	137	37.2
	Site1	5.83	1.32	0	0	0	0	8	7.4	17	15.7	6	5.6	31	28.7	46	42.6
	Site2	5.44	1.44	0	0	3	2.2	14	10.1	24	17.3	18	12.9	37	26.6	43	30.9
	Site3	5.95	1.16	0	0	1	0.8	5	4.1	10	8.3	14	11.6	43	35.5	48	39.7
Summer	Aggr.	4.42	1.80	30	7.3	37	9	61	14.8	95	23	39	9.4	91	22	60	14.5
	Site1	4.43	1.71	10	6.8	10	6.8	19	12.8	44	29.7	15	10.21	31	20.9	19	12.8
	Site2	4.17	1.73	11	7.9	13	9.4	28	20.1	28	20.1	19	13.7	28	20.1	12	8.6
	Site3	4.69	1.96	9	7.1	14	11.1	14	11.1	23	18.3	5	4	32	25.4	29	23
Autumn	Aggr.	4.1	1.60	8	3.3	31	12.8	60	24.8	51	21.1	29	12	46	19	17	7
	Site1	4.1	1.47	1	1.7	5	8.5	19	32.2	13	22	7	11.9	11	18.6	3	5.1
	Site2	4.2	1.68	4	4.5	11	12.5	17	19.3	20	22.7	12	13.6	15	17	9	10.2
	Site3	4.01	1.61	3	3.2	15	15.8	24	25.3	18	18.9	10	10.5	20	21.1	5	5.3
Combined	Aggr.	4.81	1.74	38	3.7	72	7	148	14.5	197	19.3	106	10.4	248	24.2	214	20.9
	Site1	4.85	1.69	11	3.5	15	4.8	46	14.6	74	23.5	28	8.9	73	23.2	68	21.6
	Site2	4.66	1.72	15	4.1	27	7.4	59	16.1	72	19.7	49	13.4	80	21.9	64	17.5
	Site3	4.95	1.80	12	3.5	30	8.8	43	12.6	51	14.9	29	8.5	95	27.8	82	24

By-site analytical results indicated that participants in general experienced rather similar comfort conditions between the study sites, amounting to an average of 75%. However, the total percentage of comfort votes varied with change in season. In spring and summer, the percentage of comfort votes was greater in Sites 1 and 3 with totals of, respectively, 92.6% and 95.1%. In autumn, the higher percentage of outdoor users rated for comfort categories in Site 2 recorded an average of 63.5% compared to Sites 1 and 3 with 57.6% and 55.8%, respectively.

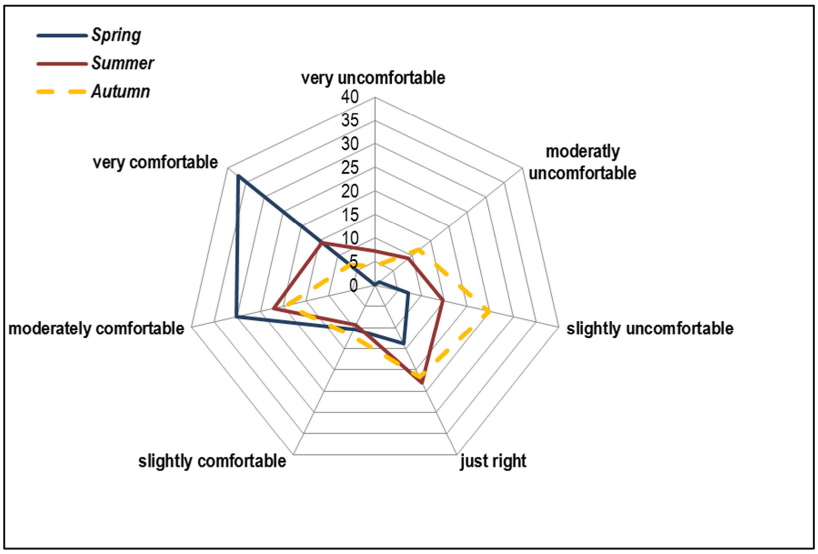


Figure 6.15. Frequency distribution of thermal comfort votes in different seasons

6.8.4 THERMAL ACCEPTANCE

The acceptance of the environmental parameters measured during the field surveys was investigated to explain the perception of thermal conditions in the RUCC study. Table 6.14 is the statistical summary of people's direct votes on the acceptability of the four environmental parameters in different seasons and sites. Overall, the findings showed that the environmental parameters were quite acceptable to outdoor users when the aggregated data are considered. Among the parameters, T_a and RH with about 91% of total votes cast for acceptable category were the most acceptable ones at the time of the field surveys. These were followed by T_{mrt} and V_a with, respectively, 85% and 81.1%.

Table 6.14. Statistical summary of direct votes on thermal acceptability in different seasons and sites

		Thermal (T_a) acceptance						T_{mrt} acceptance					
				Acceptable		Not acceptable				Acceptable		Not acceptable	
		Mean	Std dev			No	%	Mean	Std dev	No	%	No	%
Spring	aggregated	1.96	.20	347	95.6	16	4.4	1.89	.30	328	89.4	39	10.6
	Site1	1.98	.13	105	98.1	2	1.9	1.92	.28	99	91.7	9	8.3
	Site2	1.93	.24	129	93.5	9	6.5	1.91	.29	125	90.6	13	9.4
	Site3	1.96	.20	113	95.8	5	4.2	1.86	.35	104	86	17	14
Summer	aggregated	1.92	.27	377	91.5	35	8.5	1.87	.34	356	86.6	55	13.4
	Site1	1.93	.26	137	92.6	11	7.4	1.91	.29	134	90.5	14	9.4
	Site2	1.88	.32	122	88.4	16	11.6	1.82	.38	112	81.8	25	18.2
	Site3	1.94	.24	118	93.7	8	6.3	1.87	.33	110	87.3	16	12.7
Autumn	Aggr.	1.83	.38	199	82.6	41	17	1.76	.42	181	76.1	57	23.9
	Site1	1.80	.40	47	79.7	12	20.3	1.76	.42	45	76.3	14	23.7
	Site2	1.94	.28	80	90.9	7	8	1.83	.38	71	81.6	16	18.4
	Site3	1.78	.41	72	76.6	22	23.4	1.71	.45	65	70.7	27	29.3
Combined	Aggr.	1.91	.28	925	91	92	9	1.85	.35	865	85.1	151	14.9
	Site1	1.92	.27	289	92	25	8	1.88	.32	278	88.3	37	11.7
	Site2	1.91	.28	332	91	32	8.8	1.85	.35	308	85.1	54	14.9
	Site3	1.90	.29	304	89.7	35	10.3	1.82	.38	279	82.3	60	17.7

		Humidity (RH) acceptance						Wind speed (V_a) acceptance					
				Acceptable		Not acceptable				Acceptable		Not acceptable	
Spring	Aggr.	1.96	.20	348	95.6	16	4.4	1.84	.36	306	84.3	57	15.7
	Site1	1.97	.16	104	97.2	3	2.8	1.93	.25	99	93.4	7	6.6
	Site2	1.96	.20	132	95.7	6	4.3	1.83	.37	115	82.7	23	16.5
	Site3	1.94	.23	112	94.1	7	5.9	1.77	.42	92	77.3	27	22.7
Summer	Aggr.	1.90	.29	371	90.3	40	9.7	1.87	.33	358	87.1	53	129
	Site1	1.91	.27	136	91.9	12	8.1	1.85	.35	127	85.8	21	14.2
	Site2	1.83	.37	114	83.2	23	16.8	1.91	.28	125	91.2	12	8.8
	Site3	1.96	.19	121	96	5	4	1.84	.36	106	84.1	20	15.9
Autumn	Aggr.	1.86	.34	80	86	13	14	1.45	.50	51	55.4	41	44.6
	Site1	1.96	.18	57	96.6	2	3.4	1.79	.40	47	79.7	12	20.3
	Site2	1.92	.27	79	91.9	7	8.1	1.79	.40	68	79.1	18	20.9
	Site3	1.86	.34	80	86	13	14	1.45	.50	41	44.6	51	55.4
Combined	Aggr.	1.92	.26	935	91.4	78	7.6	1.81	.39	820	81.1	191	18.9
	Site1	1.95	.22	297	94.6	17	5.4	1.87	.33	273	87.2	40	12.8
	Site2	1.90	.30	325	90	36	10	1.85	.35	308	85.3	53	14.7
	Site3	1.93	.26	313	92.6	25	7.4	1.71	.45	239	70.9	95	29.1

The percentage of votes on acceptable thermal conditions varied in different seasons, such that the percentage of thermal unacceptability increased from spring to summer and autumn. In total, the outdoor users' experiences of thermal conditions were largely acceptable in spring, followed by that in summer and autumn (Table 6.14). Among the parameters measured, the most noticeable change was registered for the case of V_a between summer and autumn; in these two seasons, the percentage of unacceptability rose substantially from about 12.9% in summer to 44.6% in autumn. T_{mrt} was the second parameter and its acceptance by participants tangibly changed with the season; a rise of about 13% in thermal unacceptability was observed from spring to autumn. By-site analysis showed that on average and except for wind speed, participants voted for thermal acceptability roughly the same in different sites. Among the study sites, the frequency distribution of acceptable votes was lowest in Site 3 followed by Site 2. In the extreme instance, the difference in acceptability of wind speed in autumn between Site 3 and the two other sites was 35% (Table 6.14). Considering the aggregated data, the results showed a 17% difference in acceptability of V_a between Sites 1 and 3.

6.9 ASSOCIATION BETWEEN ENVIRONMENTAL PARAMETERS, INDICES AND THERMAL RESPONSES

Following the presentation of predictions made for comfort conditions in RUCC open spaces (Section 6.7) and thermal responses thereof (Section 6.8), a set of inferential analyses served to obtain a better understanding about the association between the environmental parameters, indices, and thermal responses. These analyses aimed to: firstly, evaluate the association between observed and calculated comfort data; secondly, compare the performance of the indices used in this study in prediction of thermal responses (i.e. thermal sensation-TSV, and mean thermal sensation votes-MTSV); thirdly, understand the association of predictions with variations in environmental parameters; and fourthly, comprehend the perceptions of different environmental parameters.

6.9.1 COMPARATIVE EVALUATION OF THERMAL INDICES IN THE PREDICTION OF THERMAL RESPONSES

To examine the performance of indices employed in this study in the prediction of thermal responses in the form of MTSV, the corresponding associations were compared.

A simple regression model was applied to the relationship between actual and predicted comfort to find the respective line of best fit. The comparison between the lines of best fit between the thermal indices and TSV over a range of T_a (12 ˚C-34 ˚C) means finding the extent of discrepancy between calculated and observed comfort. As shown in Figure 6.16, this discrepancy was marginal and nothing was registered above 0.5 unit for all indices. From the study indices PET (ß=0.23) and UTCI (ß=0.18) seemed to produce the closest predictions to the actual mean votes (ß=0.20). The slopes of the regression lines also indicate the sensitivity to changes of the index temperature. For PET the regression slope corresponded to 4.3 ˚C PET per actual thermal sensation unit, whereas in the cases of UTCI and OUT-SET* it corresponded to 5.5 ˚C and 6.2˚ C per actual TSV unit, respectively.

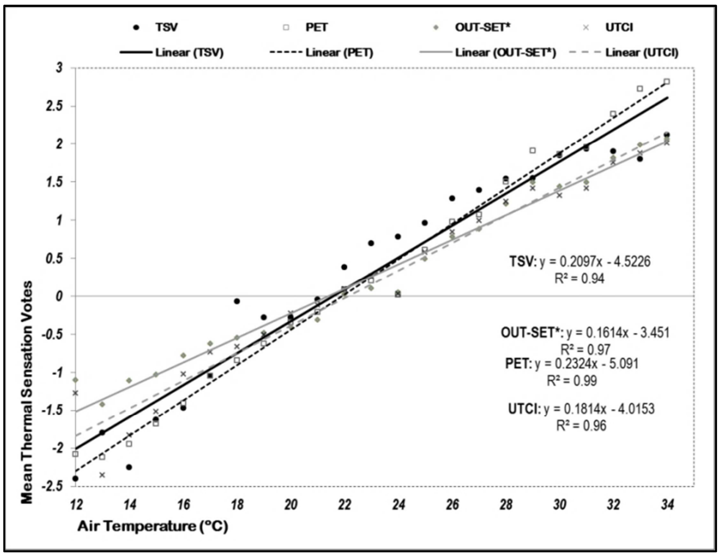


Figure 6.16. Mean binned TSV, PET, UTCI and OUT-SET* calculations on air temperature (˚C).

To further understand the prediction ability of the study indices in different seasons and to examine the association of predications with seasonal thermal sensation votes, an ordinal logistic regression model was implemented. This model is designed to explore the relationship between a continuous predictor variable and categorical outcome variable. The basis of analysis is the TSV and to examine the discrepancy between subjective comfort and calculated comfort in different seasons; furthermore, using TSV can help assess the association between index temperature and different categories of the thermal sensation scale. Included in the output are threshold, location, the significance values, and coefficient of determination. The estimates labelled as "Threshold" signify the intercept of the model; the estimates labelled as "location" are the coefficient of the predictor variables including index temperature. Table 6.15 presents the statistical summary of the ordinal logistic regression model in different seasons.

Table 6.15. The ordinal estimates for thermal comfort indices in different seasons

		PET				UTCI				OUT-SET			
	Threshold	Est.(threshold)	Sig	Est. (location)	Pseudo-R^2	Est.(threshold)	Sig	Est. (location)	Pseudo-R^2	Est.(threshold)	Sig	Est. (location)	Pseudo-R^2
Spring	[TSV = -3.0]	-1.299	.108	.20	.30	-1.661	.032	.20	.30	-1.489	.056	.21	.31
	[TSV = -2.0]	1.169	.007			.806	.044			1.001	.013		
	[TSV = -1.0]	3.409	.000			3.076	.000			3.304	.000		
	[TSV = .0]	4.235	.000			3.911	.000			4.150	.000		
	[TSV = 1.0]	5.536	.000			5.204	.000			5.460	.000		
	[TSV = 2.0]	8.147	.000			7.727	.000			7.989	.000		
Summer	[TSV = -3.0]	-.919	.403	.23	.37	-.994	.358	.24	.35	-1.783	.093	.22	.38
	[TSV = -2.0]	1.537	.002			1.485	.003			.690	.119		
	[TSV = -1.0]	4.038	.000			4.037	.000			3.267	.000		
	[TSV = .0]	5.330	.000			5.307	.000			4.603	.000		
	[TSV = 1.0]	6.819	.000			6.736	.000			6.090	.000		
	[TSV = 2.0]	9.207	.000			9.015	.000			8.381	.000		
Autumn	[TSV = -3.0]	2.083	.000	.28	.20	.323	.307	.16	.20	3.027	.000	.28	.21
	[TSV = -2.0]	3.778	.000			2.058	.000			4.742	.000		
	[TSV = -1.0]	6.092	.000			4.292	.000			7.046	.000		
	[TSV = .0]	7.278	.000			5.425	.000			8.215	.000		
	[TSV = 1.0]	8.413	.000			6.505	.000			9.330	.000		
Aggregated	[TSV = -3.0]	1.392	.000	.26	.51	.551	.011	.24	.48	1.292	.000	.24	.41
	[TSV = -2.0]	2.994	.000			2.281	.000			2.737	.000		
	[TSV = -1.0]	4.997	.000			4.279	.000			4.490	.000		
	[TSV = .0]	6.026	.000			5.253	.000			5.404	.000		
	[TSV = 1.0]	7.464	.000			6.583	.000			6.711	.000		
	[TSV = 2.0	10.126	.000			9.005	.000			9.119	.000		

Note: link function: Logit, (a) this parameter is set to zero because it is redundant

The results showed that in general PET is a better index for predicting people's thermal sensations for the aggregated data (pseudo R^2=0.51, β=0.26, P<0.001) compare to UTCI (pseudo R^2=0.48, β=0.24, P<0.001) and OUT-SET (pseudo R^2=0.41, β=0.24, P<0.001). Hence, in the following sections PET was selected for further analyses to predict thermal comfort conditions. As indicated in Chapter 2, this comfort index is widely used in outdoor thermal comfort assessment studies and its usage allows for further comparative evaluation between the results of RUCC study and that of other studies.

By-season analysis, however, proved that the prediction ability of the indices varied within different seasons. On average the best results, that is, stronger associations between calculations and thermal responses were yielded in summer when the coefficient of determination (Pseudo-R^2) of indices was higher compared to that of other seasons (Table 6.15). The estimate of the thresholds indicates the sensitivity to variation in the index temperature. By-season analysis revealed that in spring and summer the TSV categories of "neutral", "slightly warm" and "warm" were more sensitive to changes in thermal conditions.

6.9.2 ASSOCIATION OF OBSERVED AND CALCULATED COMFORT DATA

The relationship between calculated thermal comfort and subjective thermal responses (thermal sensation votes) was investigated based on mean thermal sensation votes (MTSV). As indicated previously, this measure is mainly used to reduce the effect of individual differences on the association between observed and calculated comfort data (de Dear and Fountain 1994). As depicted in Figure 6.17, simple linear regression was fitted for the mean TSV for each 2°C degree PET interval[4]. Each ensuing data pair was then weighted against the number of participants falling in that particular interval. The effect of rather large residuals of the less frequently exposed index values was minimised (de Dear and Fountain 1994). Thus, three equations were developed for the study seasons as follows:

[4] The analysis was conducted using Microsoft Excel 2010 and the Statistical Package for the Social Sciences (SPSS) Version 22. Included in the descriptive summary statistics are: Coefficient of determination (r^2), Coefficient of correlations (r) and Ordinal Logistic Pseudo-R^2.

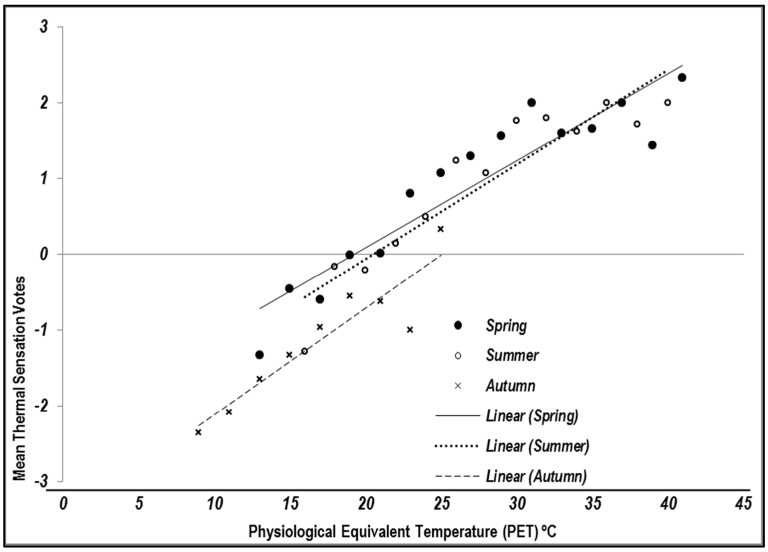


Figure 6.17. Association of the users' thermal sensation to environmental parameters

$MTSV = 0.1383X - 3.055$ **(R^2=0.91, P<0.001)** **Equation 6.1. Regression equation for combined dataset**

$MTSV = 0.1149X - 2.2116$ **(R^2=0.86, P<0.001)** **Equation 6.2. Regression equation for spring dataset**

$MTSV = 0.1251X - 2.5615$ **(R^2=0.86, P<0.001)** **Equation 6.3. Regression equation for summer dataset**

$MTSV = 0.14X - 3.5144$ **(R^2=0.85, P<0.001)** **Equation 6.4. Regression equation for autumn dataset**

The regression results suggested a strong association between subjective and calculated comfort throughout the study period as well as in different seasons (Equations 7.1. to 7.4). According to the slope of the regression equation, between the study seasons the strongest association belonged to that of autumn (β=0.14, r^2=0.85, P<0.001), followed by that of summer (β=0.12, r^2=0.86, P<0.001). This finding indicates that people's thermal sensations in spring were less sensitive to the local meteorological conditions compared to the other seasons. The characteristics of the regression models mentioned above for different seasons and indices are presented later in Section 6.11.1.1.

6.10 THE ASSOCIATION OF COMFORT INDICES, ENVIRONMENTAL PARAMETERS, AND SUBJECTIVE ASSESSMENT OF THERMAL COMFORT

It is critical to understand the individual impact of environmental parameters as well as their collective effect on different human thermal responses to and explain the patterns of thermal comfort requirements. Spearman's rank correlation analysis served to explore the association between the study environmental parameters, thermal indices and indicators of people's thermal judgment (i.e. thermal sensation, thermal preference, thermal acceptability, and overall thermal comfort) in different seasons. The Spearman's rank correlation test is appropriate for examining the relationship between an independent variable and a categorical (ordinal) dependent variable (Foster 2001).

Generally, the results revealed among the comfort scales employed in this study - "overall comfort" and "thermal acceptability" - had a negligible but significant association with PET values (r=0.12 and 0.09, P<0.001). In contrast, this association in the cases of "thermal preference" and "thermal sensation" was found to be strong and very strong, respectively (r=-0.46 and 0.72, P<0.001). This clearly shows that the latter scales better represent the impact of thermal conditions on human thermal judgement. Accordingly, these indicators of subjective comfort were the basis of the analyses carried out in the following sections as well as in Chapter 7. Table 6.16 summarises the statistics for the association between environmental parameters, indices, and comfort scales.

Table 6.16. Association between comfort scales, physical variables and indices in various seasons

	TSV (Spring)	Comfort (Spring)	TSV (Summer)	Comfort (Summer)	TSV (Autumn)	Comfort (Autumn)	TSV (Pooled)	Comfort (Pooled)
PET	.54**	.05	.60**	-.04	.45**	.20**	.71**	.1**
T_a	.58**	.02	.58**	-.05	.43**	.21**	.71**	.05
T_g	.47**	.08	.62**	-.06	.42**	.17**	.70**	.10**
V_a	-.08	-.03	-.11**	-.07	-.27**	-.12	-.1**	-.08**
RH	-.47**	-.001	-.45**	.03	-.26**	-.09	-.36**	-.20**
T_{mrt}	.36**	.09	.58**	-.07	.41**	.15**	.66**	.11**
SR	.29**	.10	.37**	.03	.23**	.09	.48**	.17**
	Acc (Spring)	**Pref (Spring)**	**Acc (Summer)**	**Pref (Summer)**	**Acc (Autumn)**	**Pref (Autumn)**	**Acc (Pooled)**	**Pref (Pooled)**
PET	-.006	-.30**	-.09	-.19**	.21**	-.20**	.08**	-.46**
T_a	.003	-.36**	-.08	-.20**	.16**	-.18*	.07*	-.5**
T_g	.13*	-.27**	-.07	-.05	.21**	-.15**	.12**	-.43**
V_a	-.20**	-.23**	.11*	-.15**	-.48**	-.36**	-.27**	-.22**
RH	-.03	.07	.2**	-.08	-.04	.04	-.02	-.010

T_{mrt}	.14**	-.17**	-.07	-.04	-.20**	-.17**	.12**	-.34**
SR	.10	-.26**	-.1*	-.02	.19**	-.12*	.08**	-.29**

Correlation is significant at the 0.05 level. Correlation is significant at the 0.01 level.

Based on the environmental parameters measured in this study, V_a, RH on one hand, and various indicators of temperature (i.e. T_{mrt}, T_a, T_g) together with SR on the other hand, had, respectively, a negative and positive correlation with all the elements of thermal perceptions. Drawing on the results presented in the table above, the following sections separately report people's perceptions of each environmental parameter.

6.10.1 PERCEPTION OF AIR TEMPERATURE

Among the environmental parameters, air, and radiant temperature (T_g) had the highest correlation with people's TSV throughout the study period (r=71, P<0.01); this association was also similar for PET values (r=0.71, P<0.01). These associations did fluctuate yet remained strong across the study seasons with correlation coefficients of 0.58 in spring and summer and 0.43 in autumn. However, except for autumn (r=20, P>0.01), air temperature had no significant relationship with "overall comfort" of open space users (P>0.05). The results of aggregated data also showed that T_a was in a strong and negative association with people's "thermal preference" (r=-0.49, P<0.01) and the strength of this association was much lower in seasonal datasets ranging from r=-0.17 (P<0.05) in autumn to –r=0.36 in spring (P<0.01). As per the relationship between "thermal acceptability" and T_a the results demonstrated a statistically meaningful yet negligible relationship for aggregated data (r=0.07, P<0.05). Among the study seasons such a meaningful relationship was only observed in autumn (r=0.16, P<0.01).

6.10.2 PERCEPTION OF WIND SPEED

The results showed that perception of wind speed in outdoor spaces differed using various thermal responses and in different seasons. The general trend proved to be a negative relationship with people's thermal judgments. Using aggregated data, the findings demonstrated that wind speed values were very weakly associated with people's "overall comfort" and "thermal sensation" for aggregated data (P<0.01). Results also showed that overall "thermal acceptability" and "thermal preference" of thermal conditions were moderately correlated to strength of wind speeds (P<0.001), with correlation coefficients of r=-0.27 and r=-0.22, respectively. By-season analysis suggested the relationship was insignificant in all study seasons for overall comfort (P>0.05), whereas in the case of TSV there were weak and moderate relationships in summer (r=-0.11, P<0.01) and autumn (r=-0.26, P<0.01), respectively. As presented in Table 6.16, the strength of the relationship for thermal acceptability and preference was significant (P<0.01). However, it varied between seasons with the largest coefficients of determination calculated for autumn amounting to r=-.38 and r=-0.44, respectively.

6.10.3 PERCEPTION OF HUMIDITY

The general trend, with one exception, "thermal preference" regarding humidity in autumn, indicated that the percentage of RH had a negative relationship with all the comfort scales (Table 6.16). The correlation of RH with TSV in overall was moderate (r=-0.34, P<0.01), with the least correlation coefficient found in autumn (r=-0.23, P<0.01) compared to the two other seasons with a strong association approximating to r=0.45. Despite the evidence for the existence of a significant association between "overall comfort" and RH values for aggregated data (r=0.29, P<0.01), no significant correlation was found in each study season. The results of the aggregated dataset suggested that overall there was no significant relationship between RH values and "preference" and "acceptability" (r=-0.01, P<0.05). By-season analysis highlighted that from these two scales only "acceptability" of RH in summer had a statistically significant relationship with RH measured during the field survey (r=0.20, P<0.01).

6.10.4 PERCEPTION OF SUN

To explore the perceptual conditions of sun by the study users the interaction of three descriptors of sunlight (i.e. T_g, T_{mrt} and SR) and various thermal responses were investigated. Overall the findings for sun descriptors had a strong and positive relationship with people's "thermal sensation" with correlation coefficients of 0.70, 0.65, and 0.48, respectively, for T_g, T_{mrt} and SR. Referring to the seasons, the strongest and weakest associations were shown in summer and autumn, respectively. The meaningful correlation of two of these parameters (T_g and T_{mrt}) with "overall comfort" was only found in autumn (r=0.16 and 0.15, P>0.01), whereas for the aggregated data these had very negligible but statistically significant relationships with comfort votes. In comparison to sun acceptability, it was found that the measures of sunlight had a noticeably higher association with people's sun preference (Table 6.16). Among the study seasons, an insignificant relationship between the sun descriptors and associated preference and acceptance votes was only reported for summer (P>0.05).

6.11 DETERMINATION OF MEASURES OF THERMAL SATISFACTION

As indicated in Chapter 2 (Section 2.8), there are three measures of thermal satisfaction with outdoor thermal environment: neutral temperature, preferred temperature and acceptable (optimal) thermal range. These measures of thermal satisfaction are recommended by comfort standards and are widely used in thermal comfort assessment studies. The following sections present the value of these measures calculated regarding the participants' thermal responses and concurrent measurements. This section also determines the thermal ranges associated to each category of thermal sensation scales and a grade of physiological heat stress.

6.11.1 THERMAL NEUTRALITIES AND PREFERRED TEMPERATURE

To further examine the characteristics of people's thermal responses and understand the level of thermal satisfaction about the assumptions enshrined in comfort standards two measures of neutral temperature and preferred temperature were calculated for the study population. These measures were calculated regarding the participants' thermal sensation and preference votes. As stated before, T_n is a temperature at which people feel neither warm nor cool and T_{pref} is a thermal point at which the majority of people require no change in current thermal conditions (McIntyre 1978). In the comfort literature, T_n is usually assumed to be the optimal temperature. Thermal comfort researchers often employ two methods to compute these thermal points: regression model (Section 6.11.1.1) and probit analytical technique (Section 6.11.1.2). The following sections present the results of calculations for these two measures using the two methods mentioned above.

6.11.1.1 Regression analysis

One way to determine the neutral temperature is to associate the mean of thermal sensation and preference votes to certain PET value bins. Hence, to produce a fairly even distribution of thermal responses frequency at each certain temperature, this study set 2 ˚C degrees of index temperature as the thermal interval. The association between thermal responses and thermal conditions was then quantified using the simple linear regression analysis. It resulted in an equation for the regression model in question. These equations were obtained and presented in Table 6.17. The T_n values for transient seasons, summer, and pooled data, therefore, were derived by dividing the value of y-intercept with the regression coefficient for different comfort indices (Table 6.17). The r-squared magnitude from the analyses for all indices produced a very strong association (R^2>0.90, p<0.001) between the calculated values and the actual mean thermal sensation votes (Table 6.17). In general, the results suggested that outdoor users had a noticeably higher neutral temperature (T_n=25.1 ˚C) in the cool season compared to the warm seasons: spring (T_n=19.2 ˚C) and summer (T_n=20.4 ˚C).

Table 6.17. Summary of linear regression model for mean thermal responses in various seasons.

	Index	Regression coefficient	Intercept	R^2	point	T_n (˚C)	Mean TSV
Pooled	PET	0.138	-3.055	0.91		22	
	UTCI	0.289	-3.291	0.94	17	19.7	0.15
	OUT-SET	0.288	-1.936	0.95		20.4	
Spring	PET	0.114	-2.211	0.86		19.2	
	UTCI	0.113	-1.836	0.90	14	16.1	0.50
	OUT-SET	0.136	-2.350	0.89		17.2	
Summer	PET	0.125	-2.561	0.86		20.4	
	UTCI	0.130	-2.488	0.92	13	19.1	0.78
	OUT-SET	0.128	-2.336	0.94		18.1	

Autumn	PET	0.14	-3.514	0.85		25.1	
	UTCI	0.086	-2.529	0.86	11	29.2	-1.47
	OUT-SET	0.143	-4.072	0.91		28.4	

Overall, PET predicted a higher value for neutral temperature (T_n= 22 ˚C) compared to other indices, however, this thermal behaviour was not consistent in all the study seasons. Unlike in summer and autumn, PET yielded the lowest neutral temperature in autumn (T_n= 25.1 ˚C); this was 4.1˚C and 3.3˚C lower than in the cases of UTCI and OUT-SET. This difference is attributed to the existence of a few more thermal intervals for UTCI and OUT-SET in lower thermal conditions that were more prevalent in autumn. Likewise, the preferred temperature was computed for the study seasons as well as the entire period of study using regression analysis; the findings are presented in Table 6.18. Among the seasons, with preferred temperature recorded as 26.5 ˚C, spring had the closest T_{pref} to that defined for the aggregated data (25.3 ˚C). Interestingly, T_{pref} in summer was noticeably cooler than the other seasons by 11.8˚C and 18.2˚C in the cases of spring and autumn, respectively. This is largely attributed to thermal preference votes mostly skewed to the "cooler" category in the Bedford scale in summer. This trend was also supported by the minimum regression coefficient (σ=-.0218) and R^2 values (0.51) found in summer.

Table 6.18. Summary of linear regression models for mean thermal responses in various seasons

	Index	Regression coefficient	Intercept	R^2	No	T_{pref} (˚C)	Mean T_{pref}
Pooled	PET	-.0451	3.1448	0.87	17	25.3	1.64
Spring	PET	-.0345	2.9120	0.76	14	26.4	2.15
Summer	PET	-.0218	2.3198	0.51	13	14.6	1.75

Autumn	PET	-.0374	3.2253	0.78	11	32.8	2.66

6.11.1.2 Probit analysis

An alternative approach to obtaining the neutral and preferred temperature is to conduct a probit analysis using the mean participants' thermal votes (Ballantyne et al. 1977). As explained in Chapter 2, in the case of neutral temperature this model (probit) categorises the seven points of the ASHRAE TSV scales into two classes: "warmer than neutral" and "cooler than neutral". Votes cast for the "neutral conditions" were equally distributed between these two classes. Similarly, the new classes for thermal preference categories were "change to lower temperature" and "change to higher temperature" and the votes cast on "no change" were evenly assigned to the groups mentioned above. The proportion of the two categories was then used as an input in the probit model yielding different probabilities that correspond to different temperature values. The index value at which a line from probability of 0.5 on y-axis intersects the two probit curves is assumed to be neutral/preferred temperature. For the aggregated data, the neutral temperature was determined to be 21.1 ˚C, 20.3 ˚C and 20.7 ˚C using PET, UTCI and OUT-SET*, respectively (Table 6.19). The results agreed well with the neutral temperature obtained from the regression equations (Table 6.18). The range of neutral temperature for the period of study was between 19.6 ˚C and 22.7 ˚C. Furthermore, it was noticed that T_n changed across the seasons with a rise in value from spring (20.4 ˚C PET) to summer (21.2 ˚C PET) and autumn (27.5 ˚C). Other characteristics of neutral temperature for the different seasons, including the 95% confidence intervals (lower and upper bands), are tabulated below (Table 6.19).

Table 6.19. Summary of probit analysis on neutral temperature in different seasons

	Index	Point	T_n (˚C)	Lower	Upper
Pooled	PET		21.1	19.6	22.7
	UTCI	17	20.3	19.7	20.9
	OUT-SET		20.7	19.8	21.7
Spring	PET		20.4	19.5	21.2
	UTCI	14	18.4	17.4	19.4
	OUT-SET		19.1	18	20

Summer	PET		21.2	18.1	23.1
	UTCI	13	20.7	19.5	21.6
	OUT-SET		19	17.8	20
Autumn	PET		27.1	22.8	41.6
	UTCI	9	33.2	25.4	-
	OUT-SET		32.2	26.5	60.9

A similar method, probit analysis, was applied to thermal preference votes in order to calculate preferred temperature. Accordingly, the thermal preference votes were then re-categorised into two groups, these being "change to lower temperature" and "change to higher temperature". Results indicated that annual preferred temperature for the RUCC study was 24.3 ˚C (Figure 6.18). This temperature falls within 2.3 ˚C and 3.2 ˚C of the T_n by regression and probit, respectively. However, it is 1.1 ˚C lower than the value of T_{pref} calculated by regression analysis.

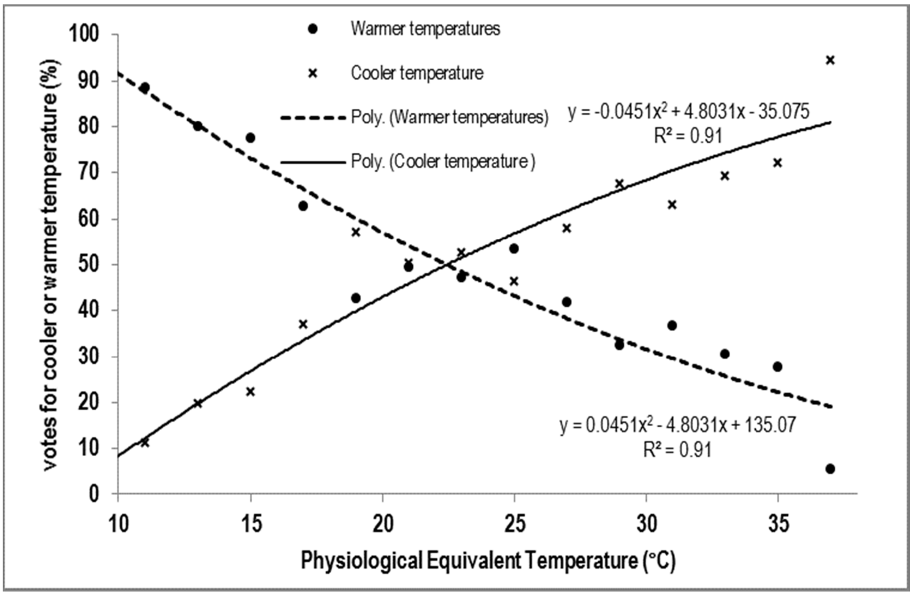


Figure 6.18. Curve for the probit model for the entire period of study

T_{pref} for the study seasons extended from 15 ˚C in summer to 32.1 ˚C in autumn. Table 6.20 summarises the findings for the characteristics of thermal preference and preferred temperature values in various seasons and indices. With the exception of values in summer, the trend of change in the values of T_{pref} in the various seasons resembled the pattern observed for the T_n values. However, the derived magnitude of temperature values obtained for preferred temperature differed markedly from the calculations for neutral temperature. In summer, this difference was within 5.4 ˚C and 6.2 ˚C of the neutral temperature by regression and probit, respectively.

Table 6.20. Summary of probit analysis on preferred temperature in different seasons

Index	No	T_{pref} (˚C)	Lower	Upper

Pooled	PET		24.3	22.4	26.3
	UTCI	17	28.8	22.3	-
	OUT-SET		26.2	23.1	31.5
Spring	PET		27.5	24.4	34.1
	UTCI	14	25.5	22.5	31.6
	OUT-SET		26.2	23	32.7
Summer	PET		15	-5.6	20
	UTCI	13	13.4	-40	19.6
	OUT-SET		14.4	-	17
Autumn	PET		32.1	23.2	-
	UTCI	9	36.8	25.4	-
	OUT-SET		33.6	25.9	-

Using the two methods of analysis, the results proved that in comparison to T_n, T_{pref} had larger values for all the study indices and seasons. Among the seasons and considering the results of regression, this difference was more evident in autumn (**Δ**=7.7 ˚C) closely followed by that in spring (**Δ**=7.2 ˚C). Furthermore, with reference to the comfort indices, UTCI exhibited the largest difference between T_n and T_{pref} by up to 7.3 ˚C in summer.

6.11.2 ACCEPTABLE (OPTIMAL) THERMAL RANGE

Acceptable thermal range or optimal thermal range is a useful tool allowing urban designers and planners to consider the climate-sensitive design principles in the development of outdoor spaces. This tool is a simple yet a valuable measure allowing urban planners (Chen and Ng 2012, Algeciras et al. 2015), designers (Yang et al. 2013b), developers of outdoor spaces (Yahia and Johansson 2013) and tourist industry authorities (Lin and Matzarakis 2008) to consider thermal comfort requirements potential users of outdoor spaces in cities while making decisions for development and usage of these built environments. As indicated before this measure was initially developed for indoor thermal conditions to specify comfort zones for building inhabitants and identify the percentage of people who perceive thermal conditions to be unacceptable and subsequently thermally dissatisfied with their thermal environment. According to definitions enshrined in the comfort standards the acceptable thermal range is where at least 80% of building occupants are satisfied (or 20% are dissatisfied) with the surrounding thermal environment (ASHRAE 55 2010). There are two common approaches to determining the acceptable thermal range: firstly, assuming the three central categories of TSV to thermal acceptability; and secondly, the use of the direct thermal acceptance scale. Subsequently, using these two approaches for the acceptable thermal range are calculated and reported below.

6.11.2.1 Central categories of thermal sensation scale

The use of this approach is the most common method to define acceptable thermal range in the comfort literature. This approach is based on the assumption that a relationship exists between thermal sensation and satisfaction. Subsequently, the cornerstone of this approach relies on considering the votes cast for three central categories of thermal sensation as acceptable thermal conditions. The three central categories are used to define the percentage of people's thermal acceptability over the various PET thermal values (ASHRAE 55 2010). A second order regression model was applied to the field study data to determine the acceptable thermal range of RUCC open spaces for the entire period of study (Figure 6.19). The percentage of thermal acceptability was calculated for PET thermal range of 9 ˚C to 35 ˚C. The regression model indicated a strong correlation, r^2=0.80 ($P<0.01$). The intersection between the lines of 80% of acceptability and the curves yielded a thermal range between 19.8 ˚C and 24.1 ˚C. This thermal range encompassed the T_n calculated for aggregated data by the linear regression model (Table 6.17) and probit regression analysis (Table 6.19). Yet this range did not cover the T_{pref} value computed using both analytical methods (Tables 7.18 and 7.20).

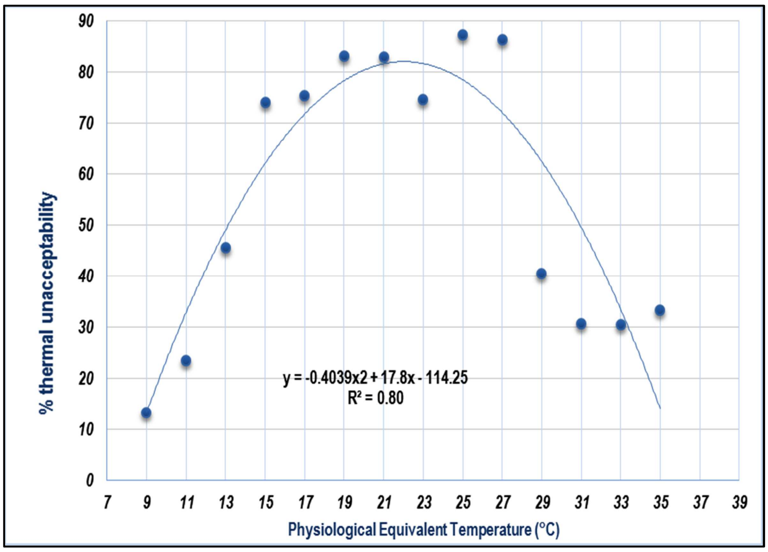


Figure 6.19. Comfort range defined using three central categories of TSV scale.

6.11.2.2 Direct vote on thermal acceptability

Despite the widespread acceptance of the ASHRAE-55 method (using thermal sensation scale), there is a debate in comfort research about its validity (Berglund 1979, Brager et al. 1993, Zhang and Zhao 2009) to determine the acceptable thermal range. Therefore, an alternative method has been suggested to better assess the extent of outdoor thermal conditions , i.e. utilising direct thermal acceptance votes (Berglund and Gonzalez 1977). The average of acceptability of thermal conditions indicated by participants that corresponded to each PET bin with a width of 2 ˚C served to define the comfort range. Similarly, a second order regression model was applied to the direct thermal acceptable votes (Figure 6.20); the model indicated a strong correlation between the percentage of thermal acceptability votes and PET values, R^2=0.82 (P<0.01).

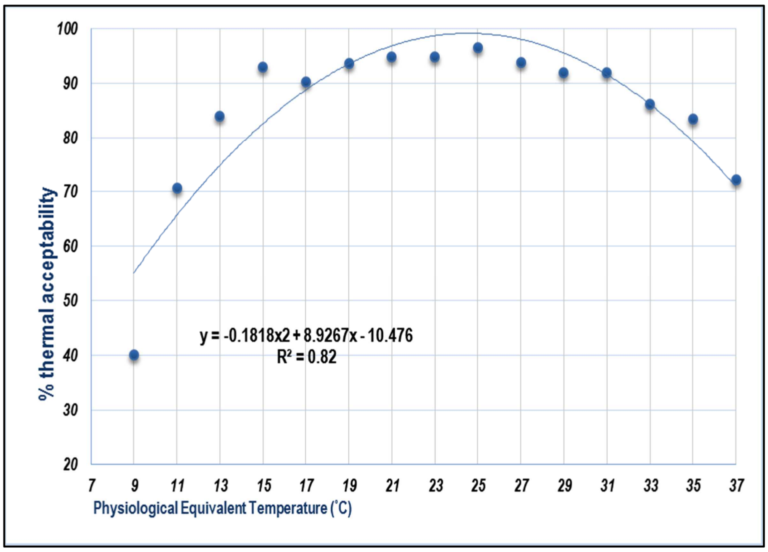


Figure 6.20. Comfort range defined based on direct votes on thermal acceptable

According to the obtained votes on direct acceptability throughout the study period and the benchmark of at least 80% of occupants satisfied with thermal environment, the comfort thermal range was 14.3 ˚C to 33.8 ˚C (Figure 6.20). This thermal range contained the T_n and T_{pref} specified for aggregated data and the study seasons computed using both linear and probit regression models.

6.12 ASSOCIATION OF THERMAL RANGES TO CATEGORIES OF THERMAL SENSATION

As discussed before, there is no comfort standard specifying the comfort conditions in outdoor settings including the relationship between values of comfort index predicted for different thermal conditions, subjective thermal assessment, and the associated grades of physiological stresses. However, such relationship should be determined as this will greatly contribute to developing policies concerned with human health and well-being in outdoor spaces. In comfort research there are two methods widely used to define thermal boundaries of thermal sensation scale: probit regression analysis (Humphreys 1975, Ballantyne et al. 1977) and use of acceptable thermal range corresponding to the feeling of "neutral" (Matzarakis and Mayer 1996b, Nikolopoulou and Lykoudis 2006, Lin and Matzarakis 2008). The practice of defining thermal boundaries is also known as calibration of thermal comfort index against different categories of thermal sensation scale.

The probit analysis was used to define the thermal boundaries between TSV categories in the RUCC open spaces. Employing the probit regression model to examine the field study data was suggested by Ballantyne et al. (1977). The procedure of this analysis includes re-categorising the thermal sensation votes into two groups (i.e. "greater than or equal to" and "less than" a particular category) and defining a thermal point at which the majority of participants (50%) would change their response from one category to the subsequent higher category. It also identifies the thermal width between two categories of the thermal sensation scale. Figure 6.21 displays the probit analysis of all the thermal sensation votes as a function of PET value. It also illustrates the characteristics of change from one category to another including thermal width. For the aggregated dataset, the transition from "cold" category to "cool" occurred at 9.4 ˚C, from "cool" to "slightly cool" at 13.2 ˚C, from "slightly cool" to "just right" at 19.4 ˚C, from "neutral" to "slightly warm" at 22.9 ˚C, from "slightly warm" to "warm" at 29.2 ˚C and from "warm to "hot" at 45 ˚C. The thermal widths were also computed for some categories as 3.8 ˚C (cool), 6.3 ˚C (slightly cool), 3.4 ˚C (neutral), 6.3 ˚C (slightly warm), and 15.8 ˚C (warm).

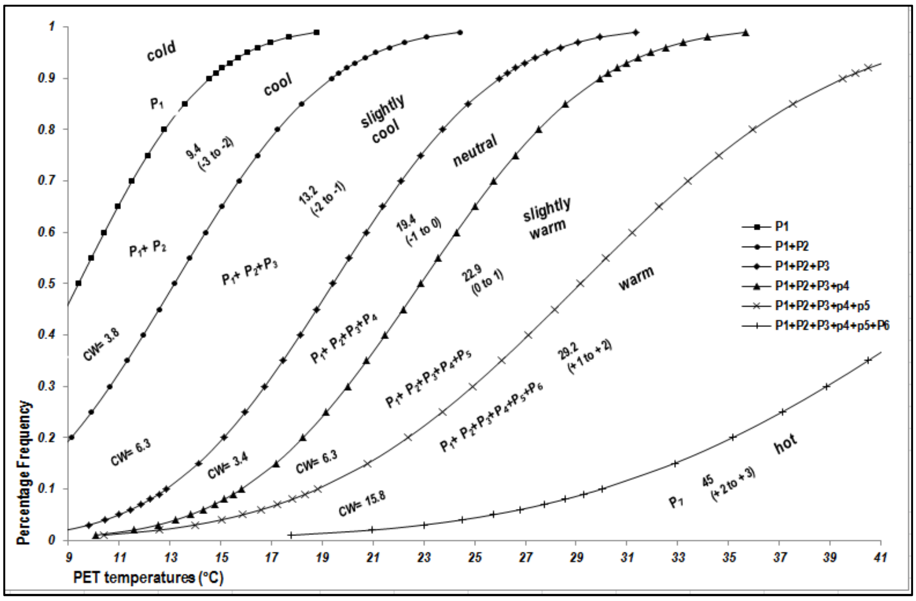


Figure 6.21. Probit analysis of aggregated thermal sensation votes over different PET values.

The alternative method to establish the relationship between different thermal conditions, thermal sensation categories and the grades of physiological stresses is based on acceptable thermal range. Here, acceptable thermal range is assumed to be the feeling of "neutral" and the ranges of "slightly warm", and "warm", and "hot" are derived through a 4˚C increase in the "neutral" range. Likewise, the ranges of "slightly cool", "cool" and "cold" are obtained through a 4˚C decrease in the "neutral" range (Lin and Matzarakis 2008). Applying this method to thermal responses, the study defined the neutral zone as 19.8-24.1 ˚C. This range matches the one derived through probit analysis (19.5- 22.9 ˚C). Table 6.21 presents the PET comfort range contained based on the two methods and compares it with that for Western/middle European (Matzarakis and Mayer 1996a) and Taiwanese residents (Lin and Matzarakis 2008). Neutral temperature values defined for the aggregated data, 22 ˚C (by probit) and 21.1 ˚C by (regression), fall within the thermal range corresponding to sensation of neutral conditions.

Table 6.21. Ranges of PET value corresponding to various grades of physiological stress

PET range for RUCC by probit (˚C)	PET range for RUCC by acceptable thermal range (˚C)	PET range for Taiwanese [a] (˚C)	PET range for western/middle European[b] (˚C)	Thermal sensation	Grade of physiological stress
-	3.5-11.5	10-14	0-4	Very cold	Extreme cold stress
≤9.4	7.6-11.6	14-18	4-8	Cold	Strong cold stress
9.5 - 13.2	11.6-15-6	18-22	8-13	Cool	Moderate cold stress
13.3 - 19.4	15.7-19.7	22-26	13-18	Slightly cool	Slight cold stress

19.5 - 22.9	19.8-24.1	26-30	18-23	Neutral	No thermal stress
23 - 29.2	24.2-28.2	30-34	23-29	Slightly warm	Slight heat stress
29.3 – 45	28.3-32.3	34-38	29-35	Warm	Moderate heat stress
>45	32.4-36.4	38-42	35-41	Hot	Strong heat stress
-	36.5-40.5	42-46	41-46	Very hot	Extreme heat stress

Source: a. (Lin and Matzarakis 2008), b: (Matzarakis and Mayer 1996a).

Using a 9-point sensation scale, this approach compared the results of this study and those reported elsewhere (Matzarakis and Mayer 1996b, Lin and Matzarakis 2008). The observed comfort range of "neutral sensation" in both approaches was rather similar to that of Western/middle European (18-23 ˚C) contexts. In comparison to the results computed for Taiwan, the results of the RUCC study proved that respondents were more tolerant of lower temperature values; however, compared to Europeans they proved to be less tolerant of such temperature values (Table 6.21).

6.13 COMPARATIVE EVALUATION OF THERMAL PERCEPTIONS BETWEEN THE STUDY SITES

Thermal perceptions of visitors of the study sites were investigated by analysing their thermal sensation, preference, and acceptance and the associated derivatives for aggregated dataset. The objective here was to shed light on the pattern of thermal satisfaction in these studies. Comparative evaluation of people's thermal judgement of different spaces not only provides information about the direct influence of given spatial design on thermal perception, but also shows how place character (i.e. aesthetic and visual characteristics, facilities, accessibility, function, opportunities to adapt to thermal conditions, type of users, etc.) may contribute to thermal judgement. The place character is probably linked with different thermal and non-thermal factors that are not fully studied. Nikolopoulou (2004b) argued that given the fact that each open space may be convenient to people, users could theoretically compromise their thermal judgement to take advantage of such comfort.

The linear regression model was applied to the entire dataset to understand the subjective thermal evaluation (thermal sensation and thermal preference) in the three study sites. In terms of thermal sensation, the overall results showed that there were slight differences between thermal sensations (Table 6.22). Compared to the conditions in Site 3, the results showed that people in sites 1 and 2 had roughly similar thermal sensations. The slopes of ensuing regressions indicated that respondents in Site 1 were more sensitive to changes in PET values. These slopes defined thermal sensitivity as changes of 4.8 ˚C, 5.1 ˚C and 5.8 ˚C PET per mean thermal sensation unit. Likewise, the differences found in the computed T_n in the case studies were marginal and approximated to 1˚C.

Table 6.22. Ssummary of regression model for thermal sensations and preference in the study sites

	Regression coefficient	Intercept	P-value	No	T_n (˚C)	Mean TSV
Thermal sensation						
SITE 1	0.207	-4.3457	0.94	313	21	0.17
SITE 2	0.194	-4.077	0.99	279	21	0.17
SITE 3	0.173	-3.4917	0.95	301	20.1	0.02
Thermal preference						
	Regression coefficient	**Intercept**	**P-value**	**No**	**T_{pref} (˚C)**	**Mean TSV**
SITE 1	-0.04	2.9997	0.40	313	25	2.07
SITE 2	-0.059	3.4533	0.87	279	24.4	2.17
SITE 3	-0.07	3.56	0.98	301	22.9	2.16

Similar trends were also found with reference to the users' thermal preference wherein people in Site 3 expressed their preference marginally differently. In general, the findings indicated that people's T_{pref} was higher than their T_n reaching 2.8 ˚C and 4˚C in the cases of Site 3 and 1, respectively. This finding again suggests that the respondents were more satisfied with higher temperature than the values computed for thermal neutrality. It also confirms the latter did not accord to individuals' thermal preference (satisfaction).

The third indicator of thermal satisfaction, acceptable thermal range, was also investigated for the study sites. To analyse the fair distribution of thermal responses and setting the comparable thermal conditions, the second order regression model was applied to the thermal sensation votes corresponding to the PET thermal range of 9 ˚C to 31 ˚C. Furthermore, as the measure of 80% thermal acceptability is not applicable in the resultant optimal ranges, 70% was selected as the basis to compare between these ranges in the study sites. The results showed that during the field surveys Site 2 had a wider range of thermal acceptability (16 -25.7 ˚C), followed by Sites 3 (17.24.7 ˚C) and 1

(16.9-22.2 ˚C). Figure 6.22 exhibits the characteristics of acceptable thermal ranges and corresponding regression equations for the study sites.

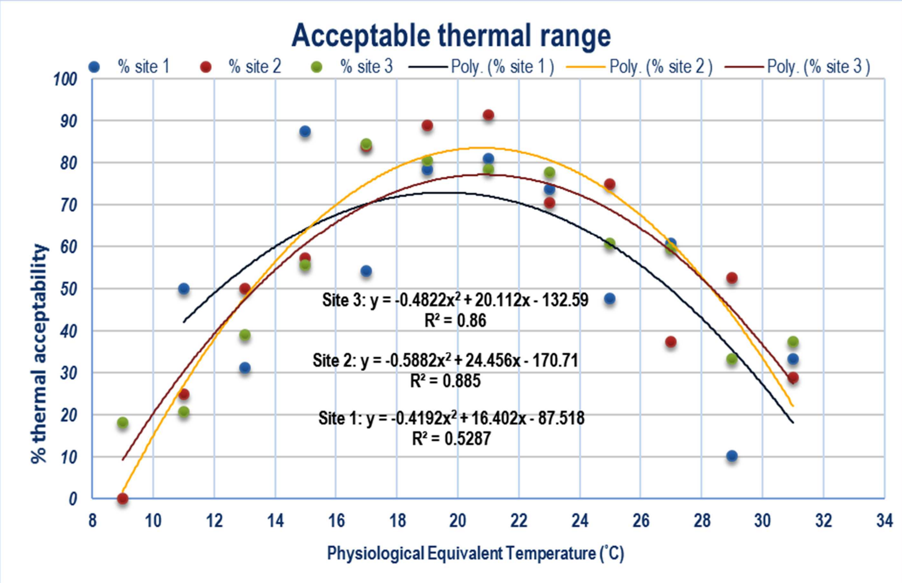


Figure 6.22. Acceptable thermal ranges for the study sites (PET: 9-31 ˚C)

Following the definition of thermal ranges and grades of thermal stresses associated with each TSV scale category (Figure 6.21), the frequency distribution of thermal stress was investigated across different seasons and sites. Figure 6.23 depicts the extent of seasonal thermal stress in each site. On average, among the study seasons autumn thermal conditions caused the greatest heat stress to spatial visitors, mostly “slight cold stress” and “moderate cold stress”. No thermal stress conditions in this season were, respectively, as little as 0% and 3.4% in Sites 3 and 2, reaching 15.3% in the case of Site 1. No thermal stress conditions were larger in spring with 52.4% (Site 1), 20.9% (Site 2) and 24% (Site 3), meaning this season provided the least stressful thermal conditions.

Drawing on the predictions, by-site analysis showed that, on average, the visitors in Site 2 were comparatively subjected to stressful thermal conditions for extended hours throughout the study period. In this Site, heat stress was noticeably perceived during summer with 92.8% graded as “slight heat stress” (30.2%) and “moderate heat stress” (62.6%), in autumn with 96.5% mostly graded as “slight cold stress” (56.8%) and “moderate cold stress” (35.2%). Moreover, the largest percentage of thermal stress in sites 1 and 3 occurred in autumn with 84.9% (incl. slight and moderate cold stress) and 100% (incl. slight, moderate and strong cold stress), respectively.

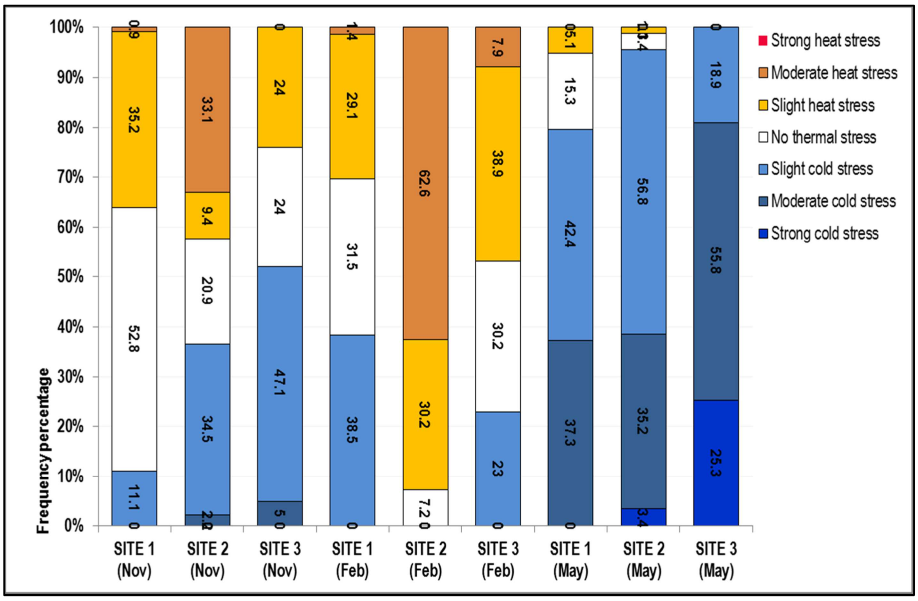


Figure 6.23. Grades of thermal stress occurring open spaces throughout study period.

As indicated before, the respondents in Site 2 were more satisfied with thermal conditions in spite of being subject to stressful thermal conditions for extended hours. This finding indicates that larger percentages of thermal votes were cast for the three central categories of thermal sensation votes (slightly warm, slightly cool and neutral). Figure 6.24 illustrates how outdoor thermal conditions were subjectively assessed by the users of the study sites within the thermal range of neutral zone (19-23 ˚C). In Site 2, more than 86% of respondents voted for one of the three central sensation categories, falling within 8.4% and 27.3% of that in sites 1 and 3, respectively. In the neutral zone, most of the visitors in Site 3 perceived thermal conditions cooler than neutral (66.4%), comprising 27.7% of votes on “slightly cool”, 34.5% on “cool” and 4.2% on “cold” categories.

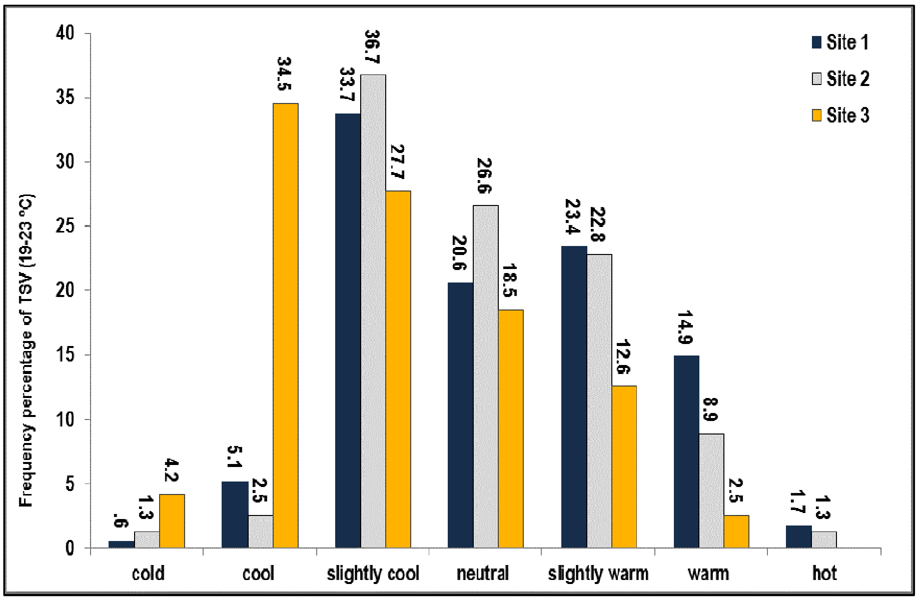


Figure 6.24. Distribution of thermal sensation votes within the neutral zone

As the field surveys in different sites was not done at the same time, three thermal ranges constituted the basis of comparative analysis on people's thermal perceptions in these sites. These thermal ranges made it possible to conduct an accurate comparative evaluation under various thermal conditions (Figure 6.21). Hence, these ranges correspond to the three categories of thermal sensation: "cooler than neutral" (13-17 °C), "neutral conditions" (19-23 °C) and "warmer than neutral" (25-31 °C). Subsequently, the pattern of participants' thermal responses on two scales of thermal perceptions (i.e. thermal preference and acceptance) was investigated for each site to explain the level of thermal satisfaction in these open spaces. The "no change" and "acceptable" votes regarding thermal preference and acceptance scales were assumed to be thermal satisfaction. Figure 6.25 shows the frequency distribution of the binomial categories of thermal preference and acceptability scales.

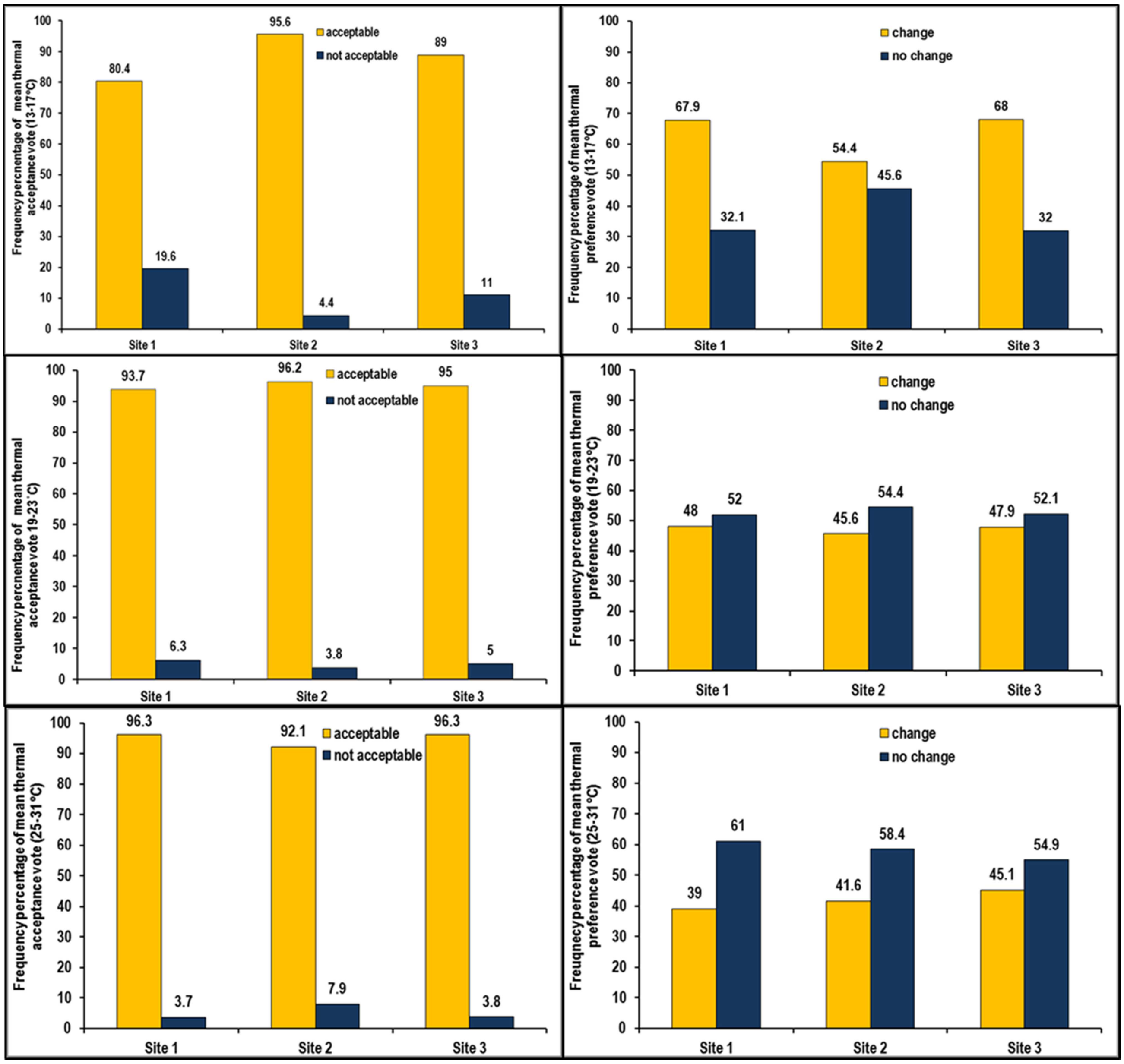


Figure 6.25. Mean thermal preference and acceptance of the study sites within three thermal ranges: Top: (13-17 ˚C), middle (19-23˚C) and bottom (25-31 ˚C).

As depicted in Figure 6.25, drawing on thermal acceptance votes, the percentage of people who were satisfied with thermal conditions was much higher than that of others in the three thermal ranges. However, except for the visitors of Site 2 having the minimum thermal unacceptability in the neutral zone, increase in PET values led to a decline in the percentage of thermal unacceptability in other sites. As per thermal preference votes, the results indicated that overall, many participants required no change in the “neutral conditions” and “warmer than neutral” ranges. Conversely, the percentage of people indicating a desire for change in current thermal conditions was larger than those who preferred otherwise.

Despite the marginal differences found among thermal responses in the study sites, the results of thermal acceptability showed that the users of Site 2 were relatively better satisfied with thermal conditions in the two first thermal ranges (13-17 ˚C and 19-23 ˚C). The results of analysis on thermal preference showed a similar tendency in which a greater percentage of people were thermally satisfied in Site 2 in the first two thermal ranges. The analytical results presented in this section proved the role of non-thermal factors in attaining thermal satisfaction in all three study sites.

6.14 CHARACTERISTICS OF USAGE PATTERN IN RUCC'S OPEN SPACES

This study employed field survey and unobtrusive observation to elicit information on usage pattern in the study outdoor spaces. In field surveys, the quality of outdoor usage was analysed using quantified parameters: purpose and frequency of visit, length of use, type of users (transient vs. non-transient), checking weather forecasts before usage, and users' opinions of spatial features. Detailed information about the characteristics of unobtrusive observation including the associated protocols devised to assess usage pattern was presented in Section 4.5.7. In total 45 days were allocated to monitor the usage pattern, consisting of 15 days of field survey and 6 days of unobtrusive observation starting from 9:00 am to 5:00 pm in each season. The distribution of days allocated for field survey and observation in each site is tabulated below (Table 6.23).

Table 6.23. The data and time of field survey and unobtrusive observation.

Site	Season	Date collection method	Time of year			Time
			Year	Month	Dates	
1	Spring	Field survey: physical measurement + questionnaire survey	2014	November	03, 06, 21	9:00 am- 5:00 pm
2		Field survey: physical measurement + questionnaire survey	2014	November	05, 07, 25	9:00 am- 5:00 pm
3		Field survey: physical measurement + questionnaire survey	2014	November	10, 11, 26	9:00 am- 5:00 pm
1		Unobtrusive observation: physical measurement+ observation of users	2014	November	13, 18	9:00 am- 5:00 pm
2		Unobtrusive observation: physical measurement+ observation of users	2014	November	14, 19	9:00 am- 5:00 pm
3		Unobtrusive observation: physical measurement+ observation of users	2014	November	17, 20	9:00 am- 5:00 pm
1	Summer	Field survey: physical measurement + questionnaire survey	2015	February	09, 12, 18	9:00 am- 5:00 pm
2		Field survey: physical measurement + questionnaire survey	2015	February	10, 13, 20	9:00 am- 5:00 pm
3		Field survey: physical measurement + questionnaire survey	2015	February	11, 16, 19	9:00 am- 5:00 pm
1		Unobtrusive observation: physical measurement+ observation of users	2015	February-March	24, 02	9:00 am- 5:00 pm
2		Unobtrusive observation: physical measurement+ observation of users	2015	February-March	25, 03	9:00 am- 5:00 pm
3		Unobtrusive observation: physical measurement+ observation of users	2015	February March	27, 04	9:00 am- 5:00 pm
1	Autumn	Field survey: physical measurement +questionnaire survey	2015	May	05, 08, 14	9:00 am- 5:00 pm
2		Field survey: physical measurement + questionnaire survey	2015	May	06, 12, 15	9:00 am- 5:00 pm
3		Field survey: physical measurement + questionnaire survey	2015	May	07, 11, 13	9:00 am- 5:00 pm
1		Unobtrusive observation: physical measurement+ observation of users	2015	May	18, 22	9:00 am- 5:00 pm
2		Unobtrusive observation: physical measurement+ observation of users	2015	May	20, 25	9:00 am- 5:00 pm
3		Unobtrusive observation: physical measurement+ observation of users	2015	May	21, 26	9:00 am- 5:00 pm

6.14.1 THE PURPOSE OF VISIT TO RUCC'S OUTDOOR SPACES

The purpose of visit to study sites was investigated using a questionnaire survey. Findings showed that the purpose of visiting differed among users of the three study sites (Figure 6.26). On average, more than 50% of use of open spaces were described as "having a break/resting" and "getting fresh air/change of environment". However, while "having a break/resting" seems to be the main purpose of visiting Sites 1 (29.6% of total use) and 3 (37.2% of total use), "passage to another place" (28.3% of total use) alongside with "having a break/resting" (26.4% of use) were the priorities for participants visiting Site 2. Playing in Site 3, which has sport facilities was accounted for 11.1% of visitors' total use; only a limited number of people used the space to get to another place (3%). Accommodating a café and many places where people could sit, Site 1 attracted the highest percentage of users for lunch/snack (20.7%). This reason to visit an open space only accounted for 11.6% and 12.6% of the percentage in Sites 2 and 3, respectively (Figure 6.26).

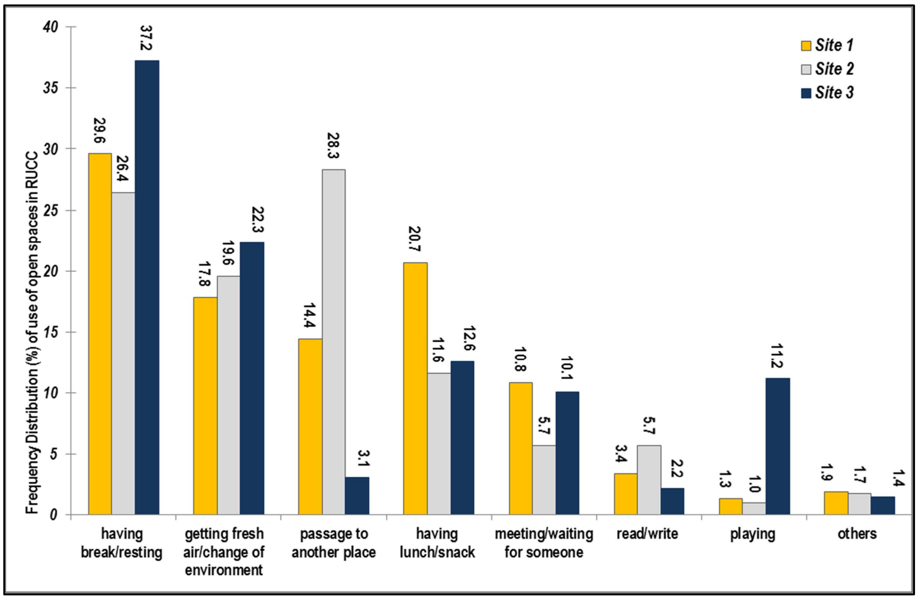


Figure 6.26. Percentage of frequency distribution for purpose of visits to the study sites.

As well as the choices provided to participants, they were asked to indicate if their purpose of visit differed from choices listed in the questionnaire. The specific purposes only took under 2% of total use in open spaces. Among other reasons, "working in or close to study open space" was registered as the primary reason (19.2%) followed by "smoking" (15.4%), despite the fact smoking is prohibited in RUCC. Table 6.24 represents those purposes of visit that were not listed in the questionnaire and were indicated by participants.

Table 6.24. Purpose of visit (other than available choices in the questionnaire)

Indicated activity by users	Count (N)	Percentage (%)
Working	5	19.2
Smoking	4	15.4
Social event	4	15.4
Exploring/site-seeing	2	7.7
Miscellaneous	8	30.8
Missing	3	11.5

6.14.2 THE LENGTH OF STAY OUTDOOR AND PREVIOUS THERMAL CONDITIONS (THERMAL HISTORY)

To understand the amount time spent outdoors prior to the questionnaire, participants were asked to specify the "length of stay" outdoors in different seasons. In total, the majority of users had consumed the study sites for short times[5], lasting from under 5 minutes to 10 minutes (68.2%). Results also indicated, respectively, large and slight differences in length of stay outdoors between sites and seasons (Table 6.25). By-season analysis proved that the greatest difference in "length of stay" was between spring and autumn when it decreased from 35% to 22%. The overall findings on the length of stay in the study outdoor spaces for each season are summarised in Table 6.25.

Table 6.25. Frequency distribution of the length of stay in outdoor spaces.

	Spring		Summer		Autumn		Combined	
	N=368		N=410		N=277		N=1053	
	No	%	No	%	No	%	No	%
Site 1								
>5	49	45.4	76	52.4	54	56.8	179	51.6
5-10	19	17.6	39	26.9	16	16.8	74	21.3
10-30	24	22.2	23	15.9	16	16.8	62	17.9
30>	16	14.8	7	4.8	9	9.5	32	9.2
Total	108	100	145	100	95	100	347	100
Site 2								
>5	74	53.2	67	48.2	45	51.7	186	51
5-10	30	21.6	39	28	18	20.7	87	23.9
10-30	18	12.9	23	16.5	14	16.1	55	15
30>	17	12.2	10	7.2	10	11.5	37	10.1
Total	139	100	139	100	87	100	365	100
Site 3								
>5	18	15	24	19.0	32	33.7	74	21.7
5-10	49	40.8	52	41.27	22	23.16	123	36
10-30	31	25.8	25	19.8	26	27.4	82	24
30>	22	18.3	25	19.8	15	15.8	62	18.2
Total	120	100	126	100	95	100	341	100
Combined								
>5	141	38.4	167	40.7	131	47.3	439	41.7
5-10	98	26.7	130	31.7	56	20.2	284	27.0
10-30	73	19.9	71	17.3	56	20.2	199	18.9
30>	55	15	42	10.2	34	12.3	131	12.4
Total	367	100	410	100	277	100		

[5] Shorter time refers to any time spent below "10 minutes" which is a combination of two choices in length of stay: "shorter than 5 mins" and "between 5 and 10 minutes".

The analytical findings indicated a noticeable variation in the time spent outdoors between RUCC open spaces (Figure 6.27). Compared to Sites 1 and 2, a higher proportion of users stayed for a longer time at Site 3 (42.2%); the period of short stay was only half of its total amount at Sites 1 (51.6%) and 2 (51.9%). The tendency to stay for a longer period in Site 3 was likely because more recreational facilities existed in this site. Figure 6.27 shows the proportion of length of stay in the three study sites.

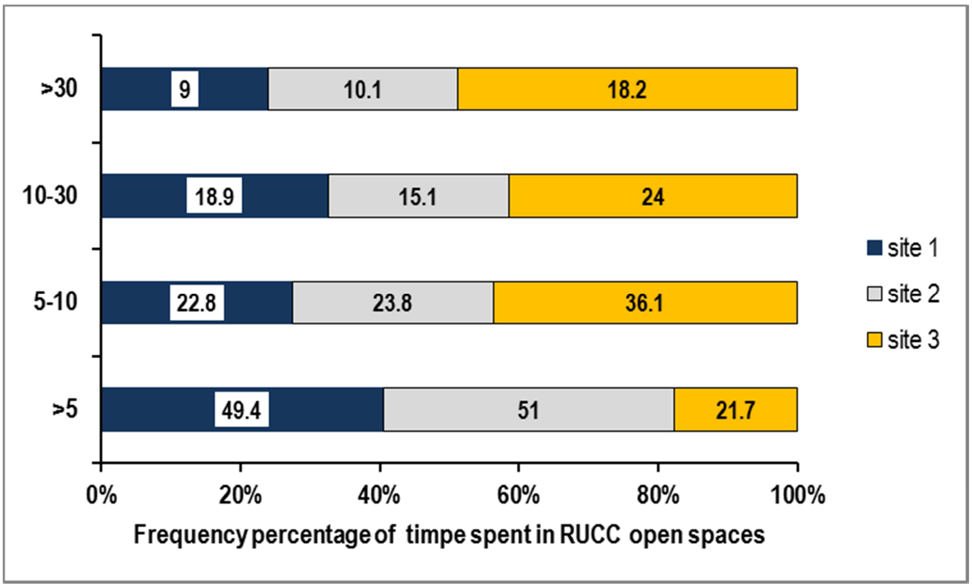


Figure 6.27. Frequency distribution of "length of stay" outdoor in RUCC.

To examine the thermal history of survey users they were asked to indicate the thermal conditions they had experienced within the last 30 mins. The multiple choices were "indoor non-ventilated space", "indoor conditioned space", "outdoor-under shade", and "outdoor-under sun". Results proved that many users (52.9%) had previously spent some time in conditioned spaces. However, some differences did emerge in people's thermal experience when they visited the sites in different seasons (Table 6.26). For instance, the percentage of users whose previous thermal conditions were conditioned was about 20% more in Site 1 than in Site 3. Table 6.26 provides the frequency distribution of people's thermal history in different sites and seasons.

Table 6.26. The frequency distribution of participants' thermal history.

	Spring	Summer	Autumn	Combined

	N=368		N=411		N=278		N=1057	
	No	%	No	%	No	%	No	%
Site 1								
Indoor non-ventilated	6	5.6	12	8.2	8	8.4	26	7.4
Indoor conditioned	68	63.0	97	66.4	53	55.8	218	62.5
Outdoor-under shade	11	10.2	17	11.3	21	22.1	49	14.0
Outdoor-under sun	23	21.3	20	13.7	13	13.7	56	16.0
Site 2								
Indoor non-ventilated	23	16.5	7	5	12	13.6	42	11.5
Indoor conditioned	74	53.2	83	59.7	39	44.3	196	53.6
Outdoor-under shade	21	15.1	32	23.	21	23.9	74	20.2
Outdoor-under sun	21	15.1	17	12.2	16	18.2	54	14.8
Site 3								
Indoor non-ventilated	14	11.6	11	8.7	9	9.5	34	9.9
Indoor conditioned	52	43	53	42.1	40	42.1	145	42.4
Outdoor-under shade	22	18.2	24	19	36	37.9	82	24.0
Outdoor-under sun	33	27.3	38	30.2	10	10.5	81	23.7
Combined								
Indoor non-ventilated	43	11.7	30	7.3	29	10.4	102	9.6
Indoor conditioned	194	52.7	233	56.7	132	47.5	559	52.9
Outdoor-under shade	54	14.7	73	17.8	78	28.1	205	19.4
Outdoor-under sun	77	20.9	75	18.2	39	14	191	18.1

6.14.3 FREQUENCY AND TYPE OF USE

To assess the characteristics of usage patterns the “frequency of use” by participants was elicited. The ensuing findings demonstrated that these sites were repeatedly frequented over the period of study with categories of “several times a week” (26.1%) and “few times a week” (27.6%). Only a small proportion of the responses fell under the categories of “rarely” (7%) and “first time” (7.4%). Frequency distribution of number of visits per week is illustrated in Figure 6.28.

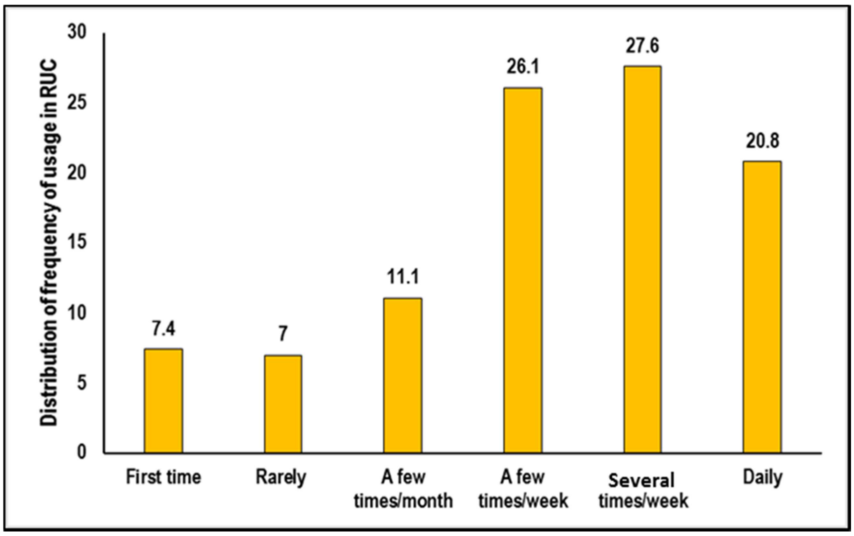


Figure 6.28. The frequency distribution of use in RUCC's open spaces.

The results also indicated that frequency of usage differed in the study sites. Site 2 was more regularly frequented by users (61.2%) than Sites 1 (38.9%) and 3 (44.6%). Conversely, among the study sites a larger number of people had their first visit to Site 3, indicating that not many RUCC students and staff used this site on a regular basis. Table 6.27 summarises the frequency of visit among the RUCC users.

Table 6.27. Summary of frequency of using open spaces in RUCC.

Frequency of use of RUCC open spaces	Site 1		Site 2		Site 3		Total	
	No	%	No	%	No	%	NO	%
Daily	58	16.6	108	29.5	55	16.1	221	20.9
Several times/week	98	28	116	31.7	78	22.8	292	27.6
A few times/week	88	25.1	75	20.5	112	32.7	275	26
A few times/month	54	15.4	32	8.7	32	9.4	118	11.2
Rarely	30	8.6	18	4.9	26	7.6	74	7
First time	22	6.3	17	4.6	39	11.4	78	7.4

The type of usage in RUCC was investigated by categorising participants into two groups: those who stayed outdoors for a short time (transient users) and those who stayed for a longer time (non-transient users). Findings for the autumn data revealed that in total more non-transient users (52.9%) attended the study sites than transient users (47.1%). However, this pattern in autumn (May 2015) was most apparent in Site 3 where the non-transient users were almost two and half times more than transient users. In contrast, in sites 1 and 2 the ratio of transients to non-transient was larger. This is in line with the findings from the time spent in study sites, where Site 3 was visited for a longer time (Figure 6.29).

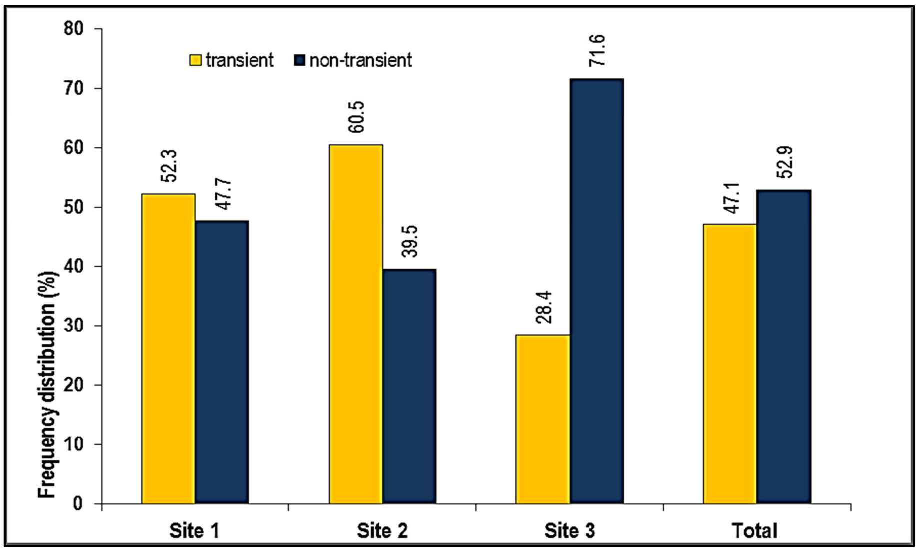


Figure 6.29. Type of use (transient vs. non-transient) of RUCC outdoor spaces in autumn.

Checking weather forecasts before visiting study outdoor spaces indicates whether the users expected what they would experience at the time of survey so that they can prepare themselves by adjusting their clothing and thermal expectations. There were many occasions, however, in which weather forecasts did not eventuate because of unforeseen variability in weather conditions in Melbourne. In autumn 2015 (May), participants indicated if they had considered the weather forecasts before leaving their homes. As illustrated in Figure 6.30, the majority of users had checked the weather conditions of the survey day, yet this differed among genders as more female participants checked the weather forecasts than their male counterparts **(Δ**=13%).

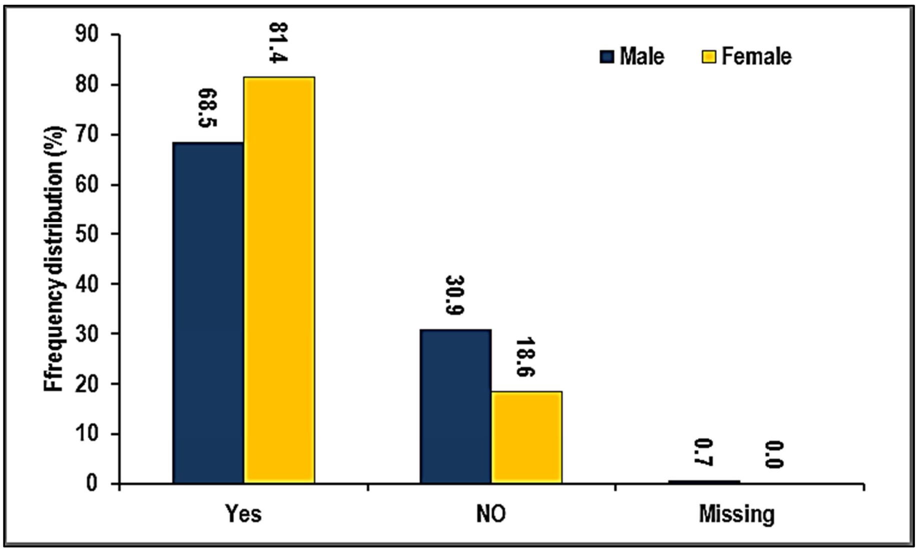


Figure 6.30. Consideration of thermal conditions before leaving home in autumn (May 2015).
Data on consideration of weather conditions is only available for autumn.

6.14.4 USERS' OPINIONS AND SPATIAL FEATURES

This study sought users' opinions on the characteristics of the site they were visiting so that the human-place relationship and usage pattern were better understood. As displayed in Figure 6.31, results showed that "having convenient access from school/workplace to" and "exposure to plants and nature" were the categories that were highly, indicated by participants as an attraction in the study sites. Apart from this, the distribution pattern of users' opinions was not similar between the study sites; Site 3 had a slightly different pattern compared to the other two sites. In Site 3, more people indicated "an environment with better ambient conditions" (22%) than those in Sites 1 (15.3%) and 2 (15.85), whereas "exposure to plants and nature" with around 25% of total frequency was less indicated by the survey population as an attractive feature in Site 3 (Figure 6.31). In addition, by-season analysis revealed a similar pattern among the survey participants in indicating the spatial features in different seasons. This pattern showed that the two categories mentioned above were similarly chosen by users as the most noticeable features of the site they had visited in different seasons (Figure 6.31).

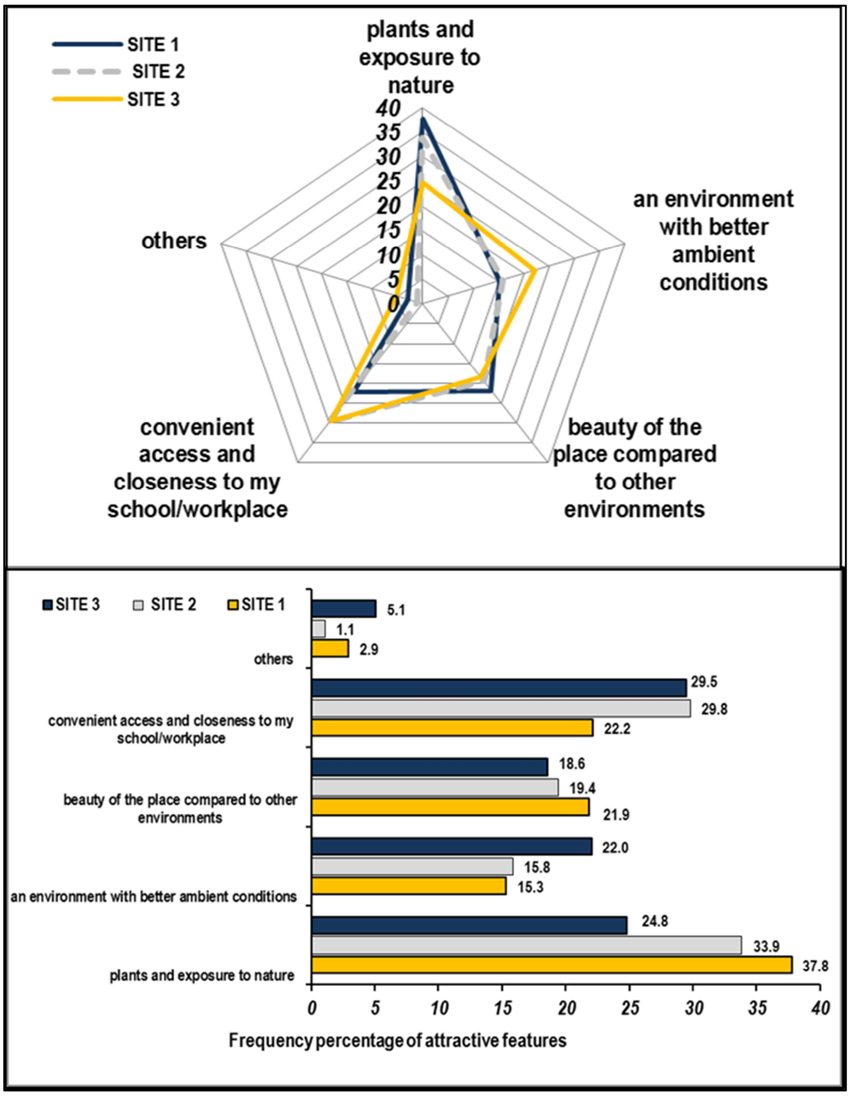


Figure 6.31. Spatial attraction in different seasons (top) and sites (below)

When the participants were asked to indicate whether they had other features on their minds that were not listed as a choice, it was found that "basketball courts" (25.5%) and "the quietness of place" (17.6%) were among the top considerations when they decided to visit them. Table 6.28 presents the statistical summary of other categories (not listed in questionnaire) specified by participants.

Table 6.28. Summary of items indicated as an attractive feature in the study sites

Indicated spatial features by users	Count	(%)
Others reasons	4	7.8
Basketball court(s)	13	25.5
BBQ facilities	6	11.8
Access to café	4	7.8
Design of place	3	5.9
Place to meet/seat	5	9.8
Quietness of the place	9	17.6
Missing	9	17.6

The study also explored outdoor users' opinions about the establishment of new green spaces in RUCC open spaces. Results showed that more than 74% of participants were in favour of establishing new green spaces at the study sites. The ratio of agreement versus disagreement remained constant within the study sites, indicating a desire for more green spaces in place regardless of the current urban configuration of these sites. Table 6.29 provides the frequency distribution of participants' opinions about new green spaces in RUCC.

Table 6.29. Users' opinions on the establishment of new natural green spaces in the study sites.

	Site 1		Site 2		Site 3		Total	
	N	%	N	%	N	%	N	%
Agree with establishment of more green spaces	260	74.3	283	77.3	245	71.8	788	74.4
No idea on the establishment of green spaces	62	17.7	61	16.7	79	23.2	202	19.3
Disagree with establishment of more green	27	7.7	21	5.7	15	4.4	63	5.9
Missing (not indicated)	1	0.3	1	0.3	2	0.6	4	0.4

6.15 UNOBTRUSIVE OBSERVATION

To better understand the human-place relationship a set of observations carried out to examine users' diurnal usage pattern in RUCC. These observations exercised with concurrent field measurements at 30-minute intervals aimed to register the number of attendants, type of activities and visitors, and their postures. Table 6.23 shows the timeframe of observations in each season and site. A copy of the observation log is shown in Appendix C. Section 4.5.7 in Chapter 4 describes the protocol and characteristics of these observations.

6.16 CHARACTERISTICS OF USAGE PATTERN

6.16.1.1 Total attendance

The analysis of data collected for total attendance suggested variations in different seasons and sites. The findings showed that in total Site 3 had the greatest number of visitors per day (N=839) throughout the study period. Considerably more people visited the spaces in summer in all study sites: 353 in Site 1, 763 in Site 2, and 1102 in Site 3.

Table 7.31 provides a statistical summary of observations during the study period with ratios of transient to total visitors included.

Table 6.30. Statistics for the daily usage pattern for transient users at 30-minute intervals.

	Spring				Summer				Autumn				Combined			
	Site 1	Site 2	Site 3	Total	Site 1	Site 2	Site 3	Total	Site 1	Site 2	Site 3	Total	Site 1	Site 2	Site 3	Total
Mean	3.9	14.2	3.6	7.2	13.1	30	6.9	16.6	5.6	23.8	5.6	14.7	9.3	27	6.2	16.5
Max	12	25	9	25	25	75	32	75	16	47	13	47	25	75	32	75
Min	0	6	0	0	1	1	0	0	0	8	2	0	0	1	0	0
Std dev	2.4	5.6	2.6	3.5	5.1	15.9	5	8.6	3.8	8.1	3.1	5.6	4.4	12	4	8
Transient	59	213	53	108	122	451	103	225	81	343	85	214	101	397	94	245
Total per day	284	289	541	371	353	763	1102	739	379	430	577	503	366	596	839	717
Ratio (%)	20.7	73.7	9.8	29.2	34.5	59.1	9.3	30.4	21.4	79.7	14.7	47.2	28	69	12	40

6.16.1.2 Transient users

The observations of visitors' attendance in different sites were organised by dividing them into two groups (transient and non-transient), and the ratio of transient users to total is reported in Table 6.30. In total, 40% of visitors to RUCC open spaces were transient; however, this ratio was highly variable among different sites and seasons. From the site point of view, the results showed that in Site 2 more than 65% of total visitors were transient, whereas they accounted for only 23% and 11% in Sites 1 and 3, respectively. This together with results presented in 7.12.3 suggests the role of spatial function in forming the usage pattern. Site 1 experienced almost the same percentage of transient visitors throughout the study period with 20.7%, 24.2% and 21.2%, respectively, in spring, summer, and autumn. It reflects the fact that seasonal conditions were not an influential factor among non-transient users. By-season analysis showed that the ratio of transient users to the total was not steady in different seasons. The percentage of transient users rose by about 17% from 30.4% in summer to 47.2% in autumn. This shows that people could barely tolerate thermal conditions outside and thus limited their visit in RUCC. This large difference in type of visit between these two seasons also reflects the fact that weather conditions do constitute a determinant of usage pattern.

6.16.1.3 Non-transient users

The following graphs (Figure 6.32) illustrate the diurnal variation in the attendance of non-transient users in different study sites and seasons. The diurnal pattern of spatial usage by non-transient visitors presented various trends among the study sites. In general, the peak of usage occurred around lunchtime (12:30 pm to 13:30 pm), when university students and staff could go to the outdoor settings and enjoy the weather. In particular, in Site 3 the pattern of diurnal attendance appeared to be steadier over the seasons with two peaks at “lunchtime” and “after 4 pm.” The visit to Sites 1 and 2, however, seemed to be more subject to seasonal change; while the frequency of usage was evenly distributed during the hours of study in spring, the maximum usage took place exclusively around lunchtime in summer and autumn.

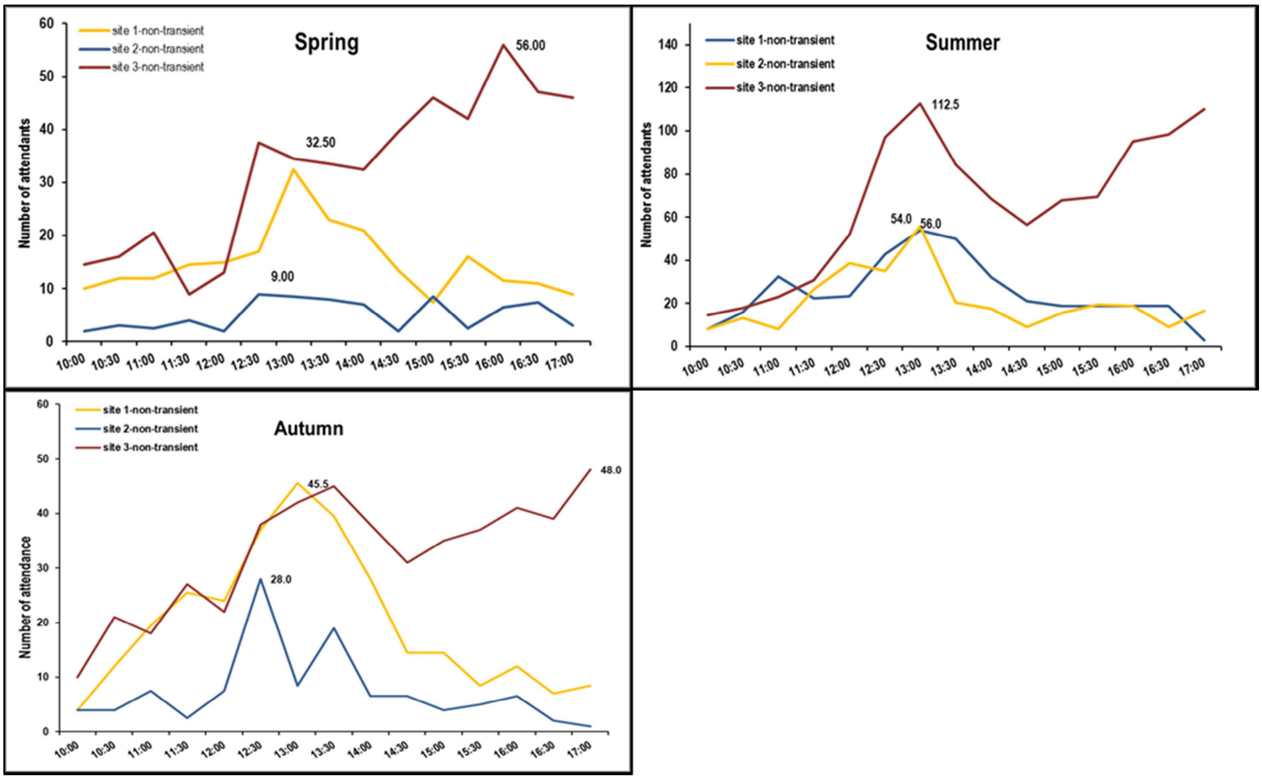


Figure 6.32. Number of attendances of non-transient users in the study sites within the period of study.

6.16.1.4 Type of activity (for non-transient visits)

Figures 6.33 to 6.35 illustrate the type of activities performed in different study sites, providing an insight into the human-place relationship. In Site 1, the two main categories of non-transient activity were "eating/drinking" and "resting" and these two accounted for more than 73% of total activities throughout the study period (Figure 6.33). This finding was mainly attributed to a café at this site, which offers an outdoor venue with tables. Interestingly, compared to summer and autumn, the percentage of "studying" in spring was subtle as the observations coincided with the end of the exams.

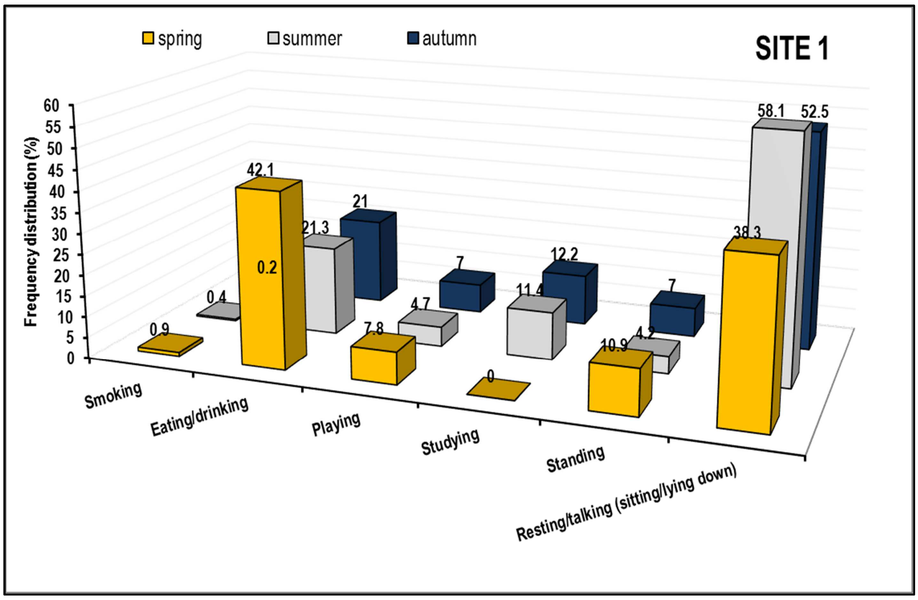


Figure 6.33. Seasonal comparison of activities occurred in Site 1.

In Site 2, "Resting/sitting" accounted for more than half of the non-transient activities in spring and summer (Figure 6.34). However, in autumn this percentage dropped by about 26% and reached almost 31%. One possible explanation for this incident is that it relates to seating facilities in this site being very cold during autumn, which made it difficult for users to sit and rest. Except for AstroTurf covered the area, almost all the other seating options had thermal properties offering cooling surfaces over the cool seasons. The turfed area was also wet during autumn and spring (refer to Table 5.2 for sitting options in this site). The second most common activity carried out in Site 2 was "eating/drinking" with more than 14.7% of total activities followed by "standing" with an average of 17.5% reaching 26.9% during autumn. This increase in the percentage of people standing was rooted in their unwillingness to sit on the cold surfaces of stone benches or lying down on the wet and muddy surface of AstroTurf.

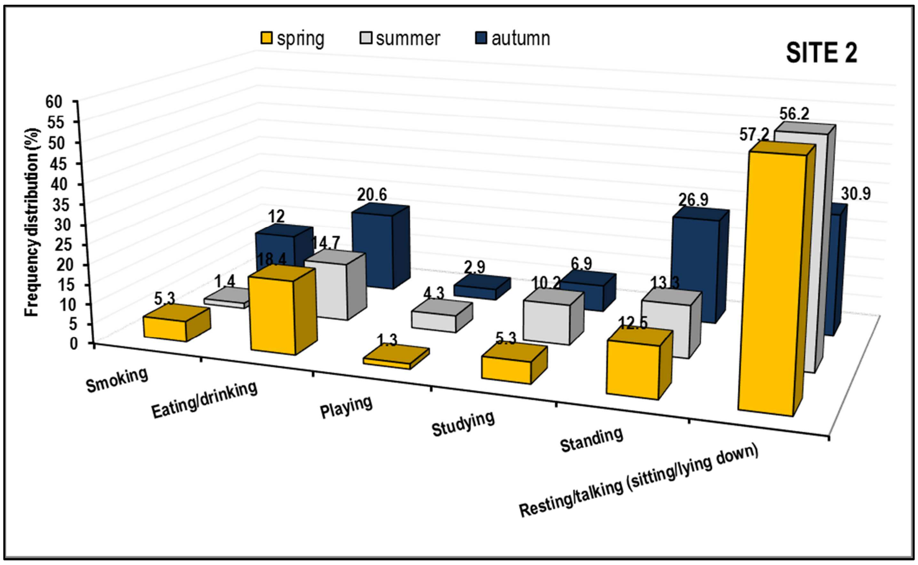


Figure 6.34. Seasonal comparison of activities occurring in Site 2.

Site 3 is a recreational space with sport and entertainment facilities that were mostly frequented by those non-transient users who tended to play sport. The majority of activities occurred during observations was "playing sports" including basketball (Figure 6.35). The percentage of players., however, varied across the study seasons where the difference approximated to 17%. This resulted from the difference between the highest percentage observed in spring (53.1%) and the lowest in summer (44%).

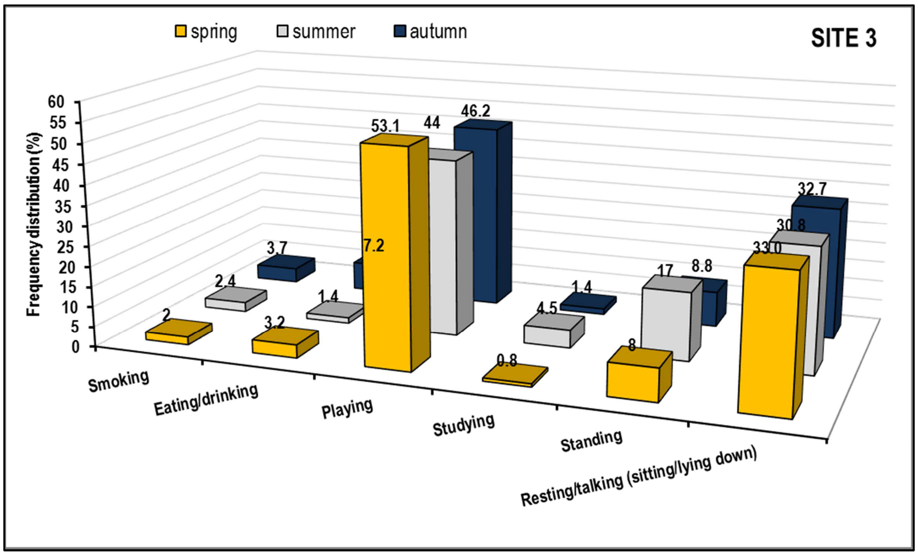


Figure 6.35. Seasonal comparison of activities occurred in Site 3.

The difference was due to the intense solar radiation occurring in summer and hitting the basketball courts. According to anecdotal evidence, the strong direct and diffuse radiation imposed heat stress on outdoor users leading to less of them wanting to play basketball. There was also an increase in those who were inclined to stand in shaded spots on the perimeters of the courts. The second most frequented category was "resting/sitting" and this remained almost equal over the study period (32%). Compared to the other sites, the category of "eating and drinking" covered a smaller proportion in activities performed in Site 3.

6.17 DETERMINANTS OF USAGE PATTERN: THERMAL CONDITIONS AND TIME OF THE DAY

As indicated in Chapter 2, in addition to thermal conditions the dynamic of usage pattern is a rather complex system involving various factors. As such, sometimes visitors to an open space may compromise thermal conditions in favour of other determinants. These determinants are very much dependent on the place character that defines spatial function, variability, features and the peak time(s) of visit during day. The two sets of analyses described below were carried out to understand the human-place relationship focusing on two determinants of presence in the outdoor environment (i.e. time of the day and weather conditions). Total attendance in the study sites as the main indicator of the usage pattern was the basis of these analyses.

6.17.1.1 Attendance and thermal conditions: by-site analysis

The results of time-series unobtrusive observation, total attendance in particular, were associated with thermal conditions to explore the impact of "time of day" and "microclimate conditions" on spatial visits. Therefore, the number of attendances was plotted against hours and PET values (Figure 6.36). To quantify the extent of the link between total attendance and these two factors a polynomial second order regression was applied to the aggregated data. The results suggested a strong relationship existed between thermal conditions and people's presence in RUCC open spaces. However, there was a disparity regarding the extent of association within the study sites. As juxtaposed in Figure 6.36, the usage pattern in Site 1 had a roughly similar association with thermal conditions (R^2=0.71, $P<0.01$) as to time of the day (R^2=0.67, $P<0.01$) throughout the study period. In Site 2, there was an opposite circumstance where the effect of thermal conditions on total attendance was weaker (R^2=0.39, $P<0.05$) than time of the day (R^2= 0.68, P<0.01). The former association was also found to be the weakest among the study sites. Similar to Site 2, the number of visitors in Site 3 was more governed by time of the day (R^2= 0.83, P<0.01) than thermal conditions (R^2=0.61, P<0.01).

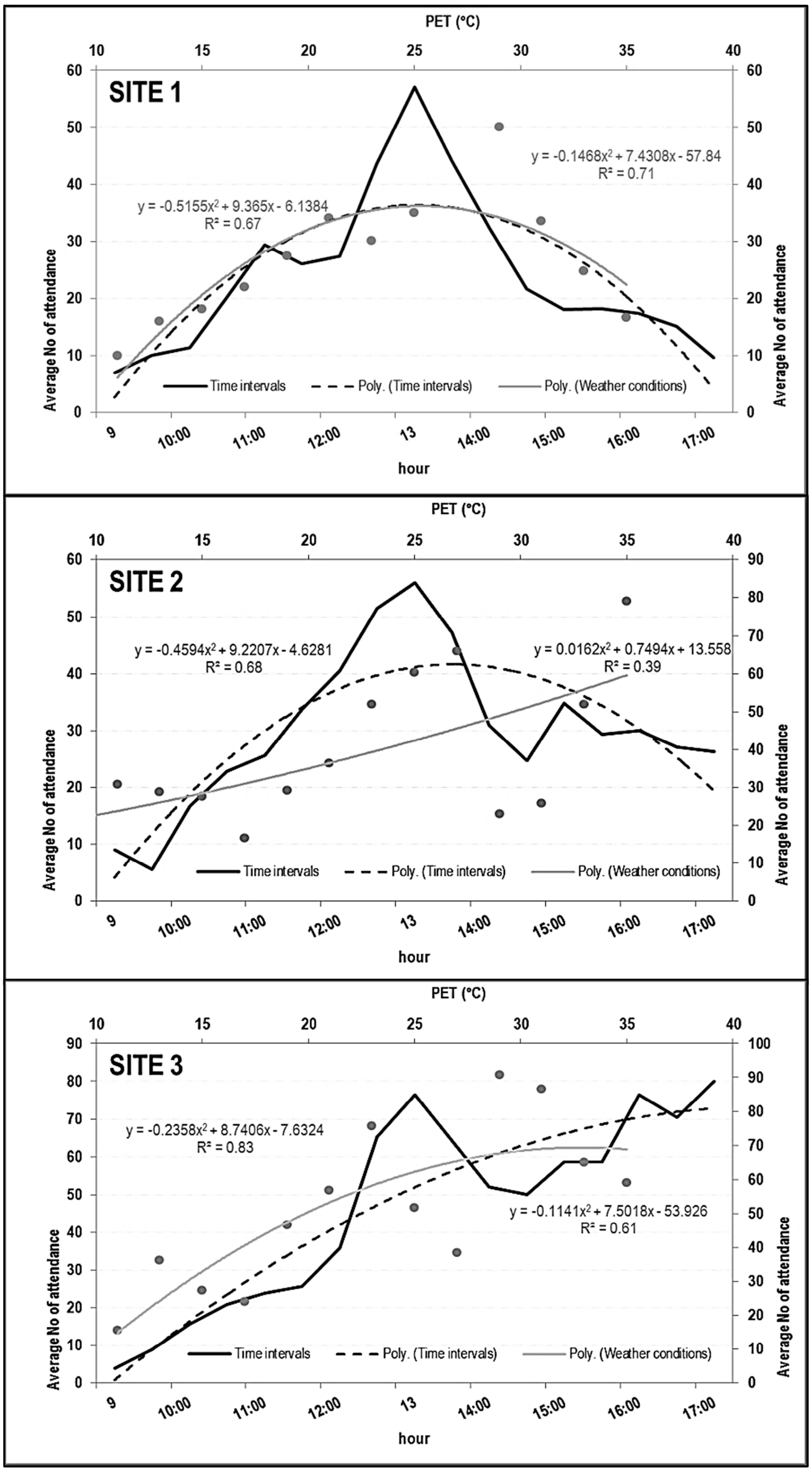
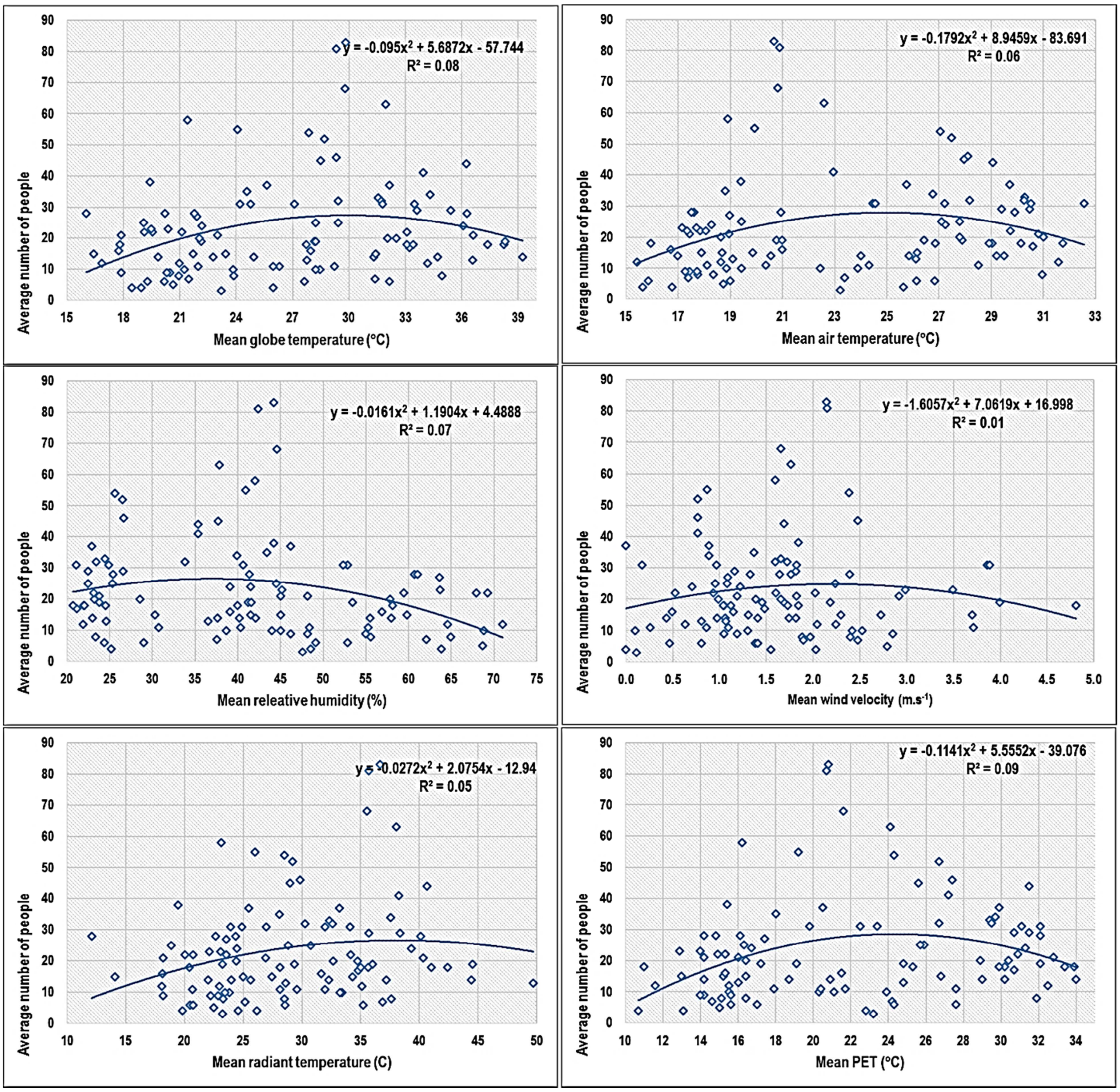


Figure 6.36. Association of total attendance to time of the day and thermal conditions

6.17.1.2 Attendance and thermal conditions: by-season analysis

The interaction between usage pattern of study sites and thermal conditions was investigated using a second-degree regression model during various seasons. This analysis involves an investigation of people's presence outdoors with reference to both individual and collective effect of environmental parameters. Figures 6.37 to 6.39



provide the findings summary on dependence of variation of number of people outdoors on the study physical parameters in different seasons.

Figure 6.37. Variation of number of people outdoors in relation to physical parameter in spring

In spring, it seemed that the mean number of people attending RUCC open spaces was not largely associated to mean PET values (R^2=0.09, N=103) and average of measured environmental parameters. In summer, the results showed a similar pattern as they did in spring (Figure 6.38), however, slightly stronger associations were found in the case of RH (R^2= 13 N=92) and T_{mrt} (R^2=12, N=92).

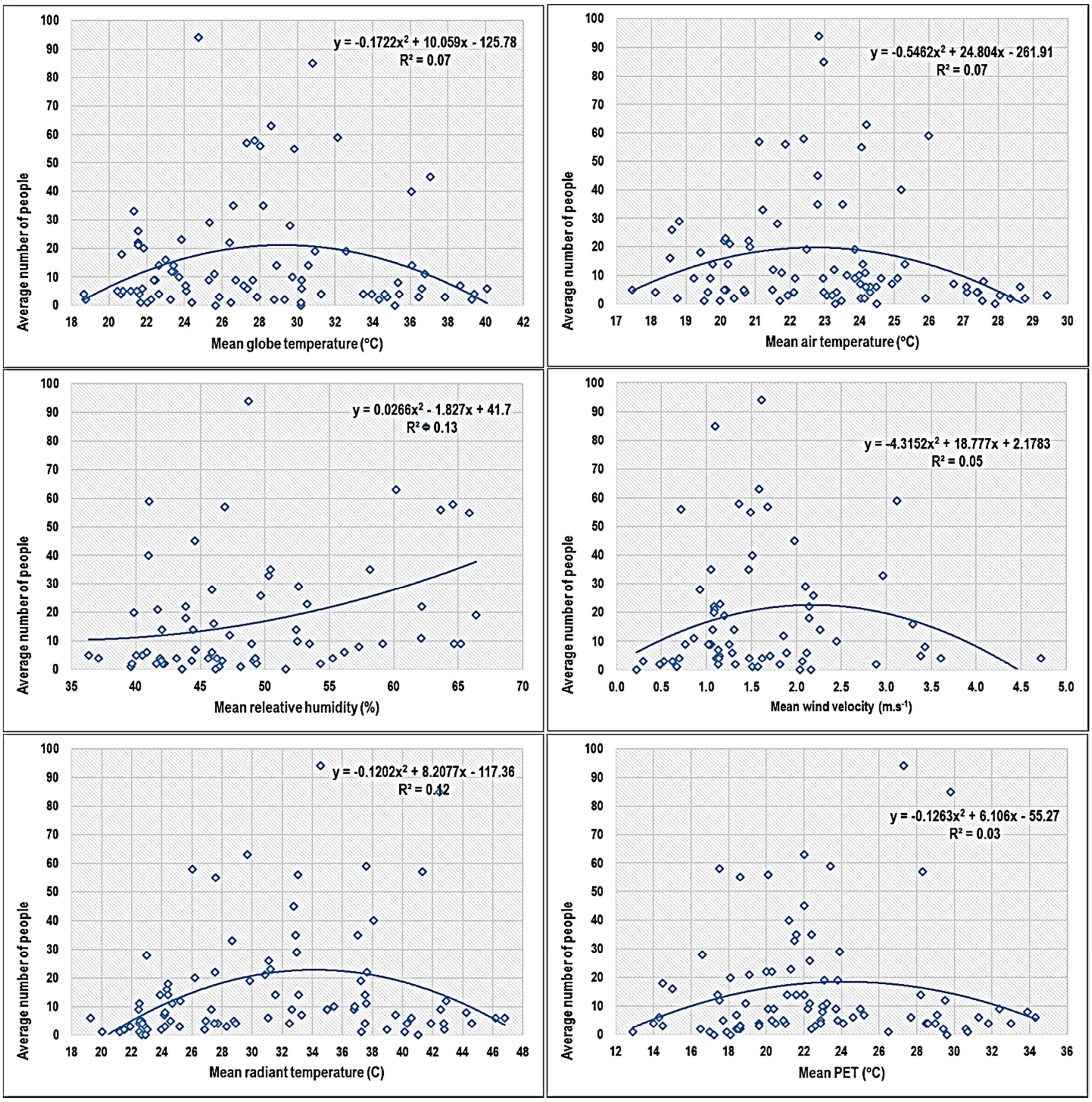


Figure 6.38. Variation of number of people outdoors in relation to physical parameter in summer

In autumn, compared to the other two seasons, weather conditions were more important factors in presence of people outdoors (Figure 6.39). For instance, mean PET values were better associated to number of people outdoors during this season (N=73,

R^2=0.13). Among the measured physical variables, T_{mrt} (R^2=0.22) and T_g (R^2=21) had the largest associations with people's presence outdoors.

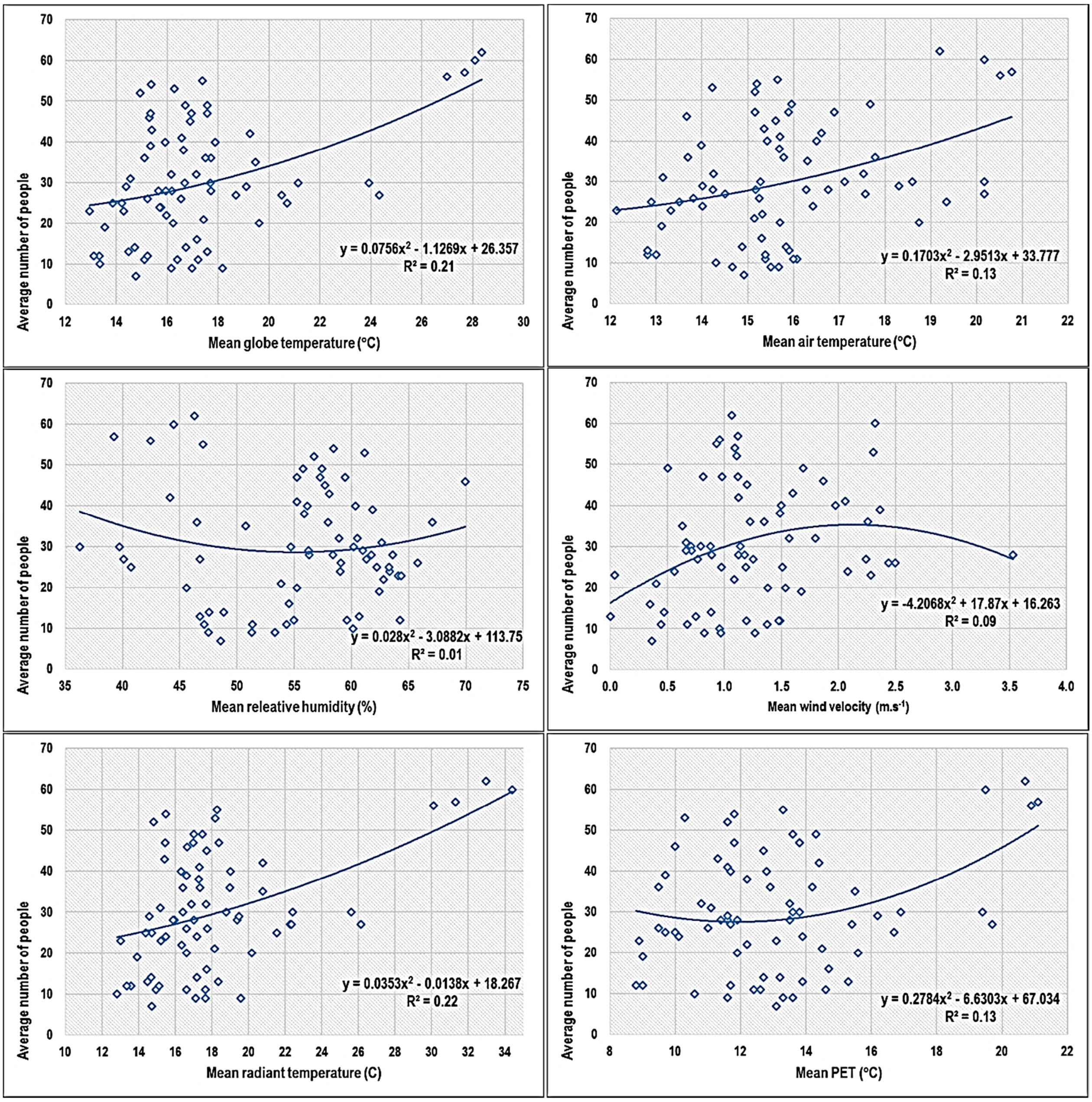


Figure 6.39. Variation of number of people outdoors in relation to physical parameter in autumn

6.18 SUMMARY

A series of field surveys was conducted from November 2014, February 2015 to May 2015 in the three open spaces of an education precinct in Melbourne. This study period was found to be representative of typical seasons for the city. The results from stationary measurements showed that there was no notable disparity in the thermal conditions among the three study sites (Table 6.2). The comparison between the thermal performance of comfort indices (PET, UTCI, OUT-SET*) showed that overall a slight difference emerged when thermal conditions were calculated (Figure 6.16). However, this difference was larger when the seasonal thermal performance was compared (Table 6.15). Generally, the analyses showed that PET had the largest relationship with the TSV (R^2=0.51, P<00.1).

Distribution and analyses of thermal responses were presented in this chapter for different seasons and sites. Using two methods of data analyses, the results demonstrated that there was a discrepancy between preferred temperature (T_{pref}) and neutral temperature (T_n) for RUCC datasets. This disparity showed that the variation of seasonal values of T_{pref} was much higher compared to that in T_n. Likewise, the other measure of thermal satisfaction, optimal thermal range, was found to be different when two thermal scales (ASHRAE thermal sensation scale and thermal acceptance) were used to compute it. The observed divergences shed light on the conceptual differences between the perceptual indicators of thermal satisfaction. Furthermore, thermal satisfaction was found to be better achieved among the visitors of Site 2, compared to those who used the other study sites.

The results presented in this chapter also delineated the usage pattern in different seasons and sites. The findings suggested that most users attended the study sites frequently (Figure 6.28) with the primary purpose of “having break/resting” and “getting fresh air/change of environment” (Figure 6.26). The visit mostly occurred for a short while (less than five minutes) (Table 6.25). By-site analyses indicated some differences in the usage patterns and with particular reference to place character. For example, compared to sites 1 and 2, a higher proportion of users at Site 3 stayed for a longer time (42.2%) (above 10 minutes). Furthermore, the users indicated that “exposure to plants and nature” along with “having convenient access from my school/workplace” were the major reasons why they visited the study sites (Figure 6.31). The results of unobtrusive observations also specified spatial usage pattern. This set of results suggested a variation in usage pattern. For instance, while Site 2 was mostly attended by transient users (65.9%) most visitors in Site 1 (77.3%) and 3 (88.6%) were non-transient (Table 6.30). By-season analysis proved that usage patterns were also determined by the time of year since the measures of attendance did noticeably fluctuate throughout the study period. As indicated in Figure 6.36, the results indicated that overall, users' attendance was both a function of "microclimate conditions" and "the time of the day". The impact of these two factors, however, varied between all three sites. Based on the analytical results, it seems that the usage of Sites 2 and 3 depended more on the time of day than thermal conditions. Conversely, in Site 1 relatively similar associations were found between these two factors and total attendance. Next chapter investigates the role of contextual factors when determining thermal perceptions.

CHAPTER 7: EFFECT OF CONTEXTUAL FACTORS ON THERMAL PERCEPTIONS

7.1 INTRODUCTION

This chapter investigates the modifying role of contextual factors on people's perceptual assessments of thermal conditions. As discussed in Chapter 4, a modified version of the socio-ecological system model (SESM) was used to analyse the effects of different contextual factors on thermal perceptions among the target population. This model assumes that various environments together with meteorological conditions determine thermal comfort and usage pattern of outdoor occupants. The model clustered a total of 26 contextual factors under five environments: individual, social, physical, psychological, and standards and policies. Of the perceptual indicators of thermal comfort, TSVs were used as the basis of analyses. Being the foundation of comfort standards and literature, this indicator allows for comparative evaluation of findings in this study with the results of other studies. The last SESM environment focuses on comprehending how the existing policies and standards may influence the way a study population perceives outdoor thermal conditions. The results of this chapter, therefore, contribute to answering the second research question: "*to what extent can contextual factors influence users' thermal perceptions?*" By presenting the evidence that proves the modifying effect of these factors, this chapter contributes to addressing the research hypothesis indicating the inadequacy of comfort standards because they ignore their effect on comfort assessments of outdoor thermal conditions.

This chapter also presents the results of by season analyses suggesting how the seasonal change may alter the impact of other contextual factors on thermal sensations. Lastly, drawing on the analytical findings, this chapter presents the evidence for thermal adaptation in three forms - physical, psychological and behavioural - that are useful for further development of adaptive comfort theory. The analysis of results in this chapter was conducted using SPSS Statistics v. 22 and Excel Spreadsheet v. 10. A range of statistical tests applied to the field study data, among others, ordinal logistic regression model (OLRM) served to find the possible statistically significant relationships between the study factors and human thermal sensation under different thermal conditions.

The unit of analysis presented in this chapter was aggregated comfort data gathered from the three study sites in different seasons. Analysing the effect of contextual factors using aggregated data ensured that various conditions including climate conditions were captured, providing a better overview of the corresponding interactions. In addition, the seasonal impact of these factors was studied to further understand how the contextual factors interacted with people and the thermal environment. This research used the ordinal logistic regression model (OLRM) to understand the modifying impact of context-specific factors on the interaction between thermal conditions and sensation in various microclimate conditions. Given that factors that influence participants' TSV in each environment are recognised, their collective influence was examined to explore the impact of each environment on thermal sensations.

7.2 INDIVIDUAL ENVIRONMENT

The analytical results presented here reflect the modifying effects of contextual factors on people's thermal perceptions through SESM five environments under various microclimate conditions. As illustrated in Chapters 4, individual environment encompasses several factors describing outdoor users' individual characteristics, which may influence thermal judgement. Included in this environment were age, gender, level of clothing insulation and activity, their skin colour and body posture. Tables 7.1 presents the findings of the OLRM for each of the above-mentioned factors clustered under individual environment; the ensuing results are reported in different sections. Included in the original logistic regression model output are threshold, location, standard error, the significance values, coefficient of determination, and odd ratio (e^x). The estimates labelled as "threshold" signify the intercept of the regression model; the estimates labelled as "location" are the coefficient of the predictor variables including the index temperature. The number of coefficient presented in the table is one less than the number of categories associated with each variable; the missing value is for the reference (control) level. Finally, the estimate of "odd ratio" indicates the ratio between the different categories (levels) of one factor to its reference level. The classification proposed for interpreting different values of coefficient of determination (pseudo R^2) is presented in Chapter 4 (Section 4.6.3). The discussions on these findings are presented in Chapter 8, Section 8.7.4.

Table 7.1. Ordinal estimates for users' thermal sensations in individual environment

Thermal sensation vote	Estimate	Std. error	Sig	e^x	N
Threshold					
[TSV (cold) = -3]	1.392	.237	.000	4.02	45
[TSV (cool) = -2]	2.994	.213	.000	19.96	102
[TSV (slightly cool) = -1]	4.997	.237	.000	147.89	262
[TSV (neutral) = .0]	6.026	.257	.000	413.80	157
[TSV (slightly warm) = 1]	7.464	.291	.000	1742.76	200
[TSV (warm) = 2]	10.126	.379	.000	24958.01	48
[TSV (warm) = 3]	0[a]	.	.	.	
Location					
PET	.269	.011	.000	1.31	1023
					916
Age					
<18-30= 1	.299	.177	.092	1.35	301
30-45=2	.704	.200	.000	2.02	157
>45=3	0[a]	.	.		.
Gender					
Male= 1	.102	.122	0.403	1.10	683
Female= 2	0[a]	.	.		340
Level of clothing insulation (clo)	-1.063	.217	.000	0.35	1023
Level of activity (met)	.55	.072	.444	1.73	1023
Skin colour					
Dark= 1	-.262	.137	.056	0.77	234
Light=2	0[a]	.	.	.	789
Posture					
Standing=1	-16.946	.135	.096	0.0	493
Sitting=2	-17.673	.000	.645	0.0	460
Lying down=3	0[a]	.	.	.	70
Exposure to sun					
In sunny spot = 1	0.717	0.134	0.000	2.04	378
Under shade =2	0[a]	.	.	.	644

Note: link function: Logit, (a) this parameter is set to zero because it is redundant [6]

7.2.1 AGE, GENDER AND THERMAL SENSATION

The initial association between the PET and TSV values when no contextual factor was added to the regression model was found to be very strong (pseudo R^2=0.51, P<0.01). Despite considering the level of clothing insulation and metabolic activity in prediction of thermal comfort when calculating thermal indices, further analyses were conducted to understand the precise role of these factors in the development of users' thermal perceptions. The level of activity and clothing insulation were examined through a

6 SPSS Software Package 22 assumes the last category as the reference index and sets it to zero to be compared with other categories and therefore the statistics will not be shown for the reference category.

questionnaire survey and supplementary observation, respectively. The level of activity was derived by the participants' indication of their last activity within the last 30–60 min prior to the field survey. The activities could be chosen from choices of walking, standing, sitting, sleeping, and playing. The clothing insulation of the participants was collected by the researcher according to the table of garment insulation values recommended by ASHRAE 55 (2010) and the sum of the values for the three human body's parts: upper, lower body and feet. To understand the effect of these two factors on thermal sensation the ordinal regression model was tested (Table 7.1). Results indicated that there was a statistical relationship between TSV and clothing insulation ($P<0.001$), whereas no evidence was found to indicate the statistically significant relationship between TSV and the level of activity ($P>0.05$).

Furthermore, a one-way ANOVA was also conducted to compare genders' and age groups' clothing patterns. The results showed that there was a statistically meaningful difference between the clothing worn by people of various ages ($F(2, 1023) = 3.85$) and genders at the $P<0.05$ significance level: ($F(1, 1021) = 9.83$).

7.2.2 CLOTHING INSULATION, ACTIVITY LEVEL AND THERMAL SENSATION

Despite consideration of level of clothing insulation and metabolic activity in prediction of thermal comfort using thermal indices, further analyses were conducted to understand the precise role of these factors on users' thermal perception. The level of activity and clothing insulation were examined through questionnaire survey and supplementary observation, respectively. The level of activity was derived by the participants' indication of their last activity within the last 30–60 min prior to the field survey. The activities could be chosen from choices of walking, standing, sitting, sleeping, and playing. The clothing insulation of the participants were evaluated according to the table of garment insulation values recommended by ASHRAE 55 (2010) and the sum of the values for the three body's parts: upper, lower body and feet.

A one-way ANOVA was also conducted to compare genders and different age group clothing patterns. The results showed that there was a statistical meaningful difference between the clothing worn by people with various ages ($F(2, 1023) = 3.85$, $P<0.05$,) and genders at the $P<0.05$ significant level: ($F(1, 1021) = 9.83$, $P<0.01$). To understand the effect of these two factors on thermal sensation the ordinal regression model was tested (Table 7.1). The results indicated that there was a statistical relationship between TSV and the clothing insulation ($P<0.001$), whereas no evidence was found to indicate the statistically significant relationship between TSV and the level of activity ($P>0.05$).

7.2.3 SKIN COLOUR, POSTURE, EXPOSURE TO SUN AND THERMAL SENSATION

The role of the participants' skin colour (white and dark), posture (standing, sitting, lying down) and the quality of their exposure to the sun (in a sunny spot, under shade) at the time of survey on outdoor thermal sensation was assessed using the ordinal regression test (Table 7.1). In the sample population, there were almost three times more people with white skin (77%) than dark-skinned (33%). The body's posture is assumed to be an important factor in the way people perceive surrounding thermal conditions; three major postures were identified for the study participants: sitting (48.2%), standing (45%), and lying down (6.8%). The results of ordinal regression showed that skin colour was not statistically effective in the variation of TSV ($P=0.05$). However, the closeness of its P-value to the significance level of 0.05 means this variable can be included in the overall regression model. The results also indicated that compared to people with light skin, dark-skinned participants were less sensitive to changes in thermal conditions ($e^x=0.77$). The OLRM results regarding the two other factors, suggested the significant and insignificant effect of the participants' exposure to sun ($P<0.001$) and posture ($P>0.05$), respectively (Table 7.1). Furthermore, the results suggested that participants who were in sunny spots were probably almost twice more sensitive to changes in thermal conditions ($e^x=2.04$).

Taking the factors that have a statistically significant relationship with TSV into account, the OLRM showed an improvement in prediction ability of the individual predictor variables (Table 7.2). This improvement was computed to be 3.5% and according to the Nagelkerke's pseudo-R^2 classification (Delhey and Newton 2002) has little influence. Table 7.2 presents the results of overall OLRM established for individual environment.

Table 7.2. Summary of the overall logistic regression model for individual environment

Thermal sensation vote	Estimate	Std. error	Sig	e^x	pseudo-R^2
Location					
PET	.235	.012	.0	1.26	51.60
Age					54.90
<18-30 = 1	.353	.179	048	1.42	
30-45 =2	.748	.202	.0	2.11	
>45 =3	0[a]	.	.	.	
Effect of exposure to sun					53.00
In sunny spot = 1	.775	.135	.0	2.17	
Under shade = 2	0[a]	.		.	
Level of clothing insulation	-1.065	.218	.0	0.34	54.30
Skin colour					55.1
Dark = 1	-.291	.139	.036	0.74	
Light =2	0[a]	. .	.		

Note: Link function: Logit, (a) this parameter is set to zero because it is redundant

7.3 SOCIAL ENVIRONMENT

The second environment of SESM includes those factors pertaining to the social aspects of thermal comfort. This environment consists of three factors (companionship, position, and climatic background) indicating the importance of social conditions in the creation of thermal perceptions in outdoor spaces. The ordinal regression model served to explore the role of social environment on people's thermal sensations. The corresponding discussions on the findings in social environment are presented in Chapter 8, Section 8.7.5.

7.3.1 USERS' POSITION, COMPANIONSHIP AND THERMAL SENSATION

The influence of two social factors (position and companionship of the participants) on thermal sensation of the survey population was evaluated (Table 7.3). The initial four groups of users, i.e. students (N= 644), professional staff (N=126), academic (N=73) and visitors (N=176) were merged into two groups: Group 1 (those who were engaged with university activities, N=843), and Group 2 (those who only visited the sites, N=176). The type of companionship was also categorised into two main groups: Group 1 (participants who were alone, N= 523) and Group 2 (those who were accompanied, N=500). Findings showed that these two factors had significant relationships with TSVs under various thermal conditions (P<0.05). The measure of odds ratio for these two parameters showed that probability of change in the TSV of non-academic participants (e^x=0.73) and those who had company while visiting the study open spaces (e^x=0.79) with reference to thermal conditions was more than respectively those who were academic and had no company. Table 7.3 summarises the statistics of ordinal regression analysis for factors clustered under social environment.

Table 7.3. Ordinal estimates for users' thermal sensations in social environment

Thermal sensation vote	Estimate	Std. error	Sig	e^x	N
Threshold					
[TSV (cold) = -3]	1.392	.237	.00	4.02	45
[TSV (cool) = -2]	2.994	.213	.00	19.96	102
[TSV (slightly cool) = -1]	4.997	.237	.00	147.89	262
[TSV (neutral) = .0]	6.026	.257	.00	413.80	157
[TSV (slightly warm) = 1]	7.464	.291	.00	1742.76	200
[TSV (warm) = 2]	10.126	.379	.00	24958.01	48
[TSV (warm) = 3]	0[a]	.	.	.	
Location					
PET	.269	.011	.00	1.31	1023
Companionship					
Alone= 1	-.233	.115	.042	0.79	523
Accompanied= 2	0[a]	.	.	.	500
Position					
Academic (1)	-.315	.152	.038	0.73	843
Non-Academic (2)	0[a]	.	.	.	176
Climatic background					
Tropical=1	-1.389	.293	.00	0.25	182
Dry=2	-1.202	.324	.00	0.30	96
Temperate=3	-.816	.273	.003	0.44	652
Cold=4	0[a]	.	.	.	49

Note: link function: Logit, (a) this parameter is set to zero because it is redundant

7.3.2 CLIMATIC BACKGROUND AND THERMAL SENSATION

The third social factor in this study, climatic background, was investigated by asking participants to indicate their place of birth; they were accordingly allocated into four categories (tropical, dry, temperature and cold) that corresponded to the main five groups of Koppen-Geiger's climate classification (Peel et al. 2007). The polar region, however, was excluded from the analysis, as no one had come from that region during the field survey. The frequency distribution of participants from these four categories is presented in Figure 7.1. The distribution of thermal responses showed that the votes cast by people from tropical regions were mostly skewed to the cooler side of the TSV scale (52%), while more people from cold regions voted for its warmer side (61%). Linking thermal acceptability to the three central categories of TSV scale, the results showed that people from arid regions expressed the highest level of acceptance of current climate conditions (62.5%).

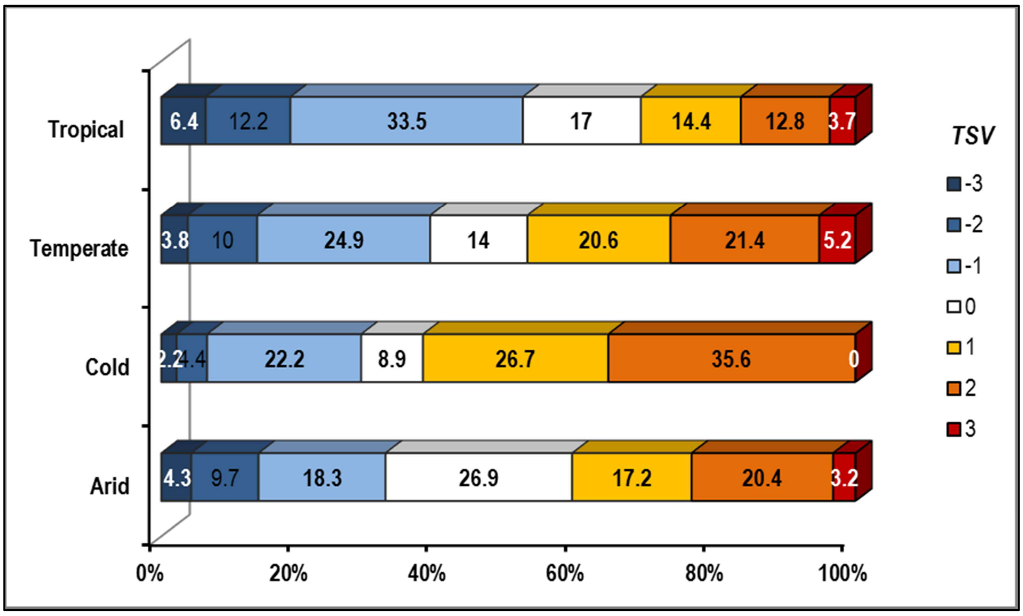


Figure 7.1. Distribution of TSV among people with diverse cultural (climate) backgrounds

As presented in Table 7.3, the OLRM results illustrate the differences in TSVs within the study climate groups (P<0.001). This finding shows that climatic background did determine people's thermal sensations in outdoor spaces. The results of odds ratio also revealed that people from a cold climatic background were more sensitive to changes in thermal conditions in Melbourne than any other group across the three study seasons. The three social factors that had statistically significant modifying factors impact on people's TSV were therefore included in the overall regression model. In this model (Table 7.4) the results showed that the coefficient of determination improved by 2% when these moderators were added to it. According to the Nagelkerke's classification of pseudo-R^2 the influence of social environment is interpreted as wielding little influence. Table 7.4 summarises the results of the OLRM test within the social environment.

Table 7.4. Summary of the overall logistic regression model for social environment

Thermal sensation vote	Estimate	Std. error	sig	e^x	pseudo-R^2
Location					
PET	.274	.012	.00	1.32	51.6
Climatic background					53.2
Tropical=1	-1.414	.293	.00	0.24	
Dry=2	-1.260	.325	.00	0.28	
Temperate=3	-.855	.274	.002	0.43	
Cold=4	0[a]				
Position					53.3
Academic =1	-.314	.153	.040	0.73	
Non-Academic=2	0[a]				
Companionship					
Alone= 1	-.294	.116	.011	0.75	53.6
Two people or more= 2	0[a]				

Note: (a) this parameter is set to zero because it is redundant

7.4 PHYSICAL ENVIRONMENT

The third environment of SESM is concerned with the physical aspects of thermal sensation in outdoor spaces. Included in this environment were the solar radiation and collective effect of four environmental parameters (T_a, RH, T_{mrt} and V_a) in the form of PET occurring during the field survey, the spatial design feature (i.e. SVF) and the indicators of physical adaptation (i.e. length of residence and time of exposure). OLRM investigated the relationship between these factors and people's thermal sensation votes.

7.4.1 ENVIRONMENTAL VARIABLES AND THERMAL SENSATION

As indicated previously, users' thermal sensation was significantly influenced by the four environmental variables expressed through PET (α=0.27, P<0.001). In addition, the intensity of solar radiations as a continuous predictor variable was found to be statistically significant (α=0.001, P<0.001). Table 7.5 summarises the statistics of the OLRM for the factors clustered under physical environment.

Table 7.5. Ordinal estimates for users' thermal sensations in physical environment

Thermal sensation vote	Est.	Std. error	Sig	e^x	N
Threshold					
[TSV (cold) = -3]	1.392	.237	.00	4.02	45
[TSV (cool) = -2]	2.994	.213	.00	19.96	102
[TSV (slightly cool) = -1]	4.997	.237	.00	147.89	262
[TSV (neutral) = .0]	6.026	.257	.00	413.80	157
[TSV (slightly warm) = 1]	7.464	.291	.00	1742.76	200
[TSV (warm) = 2]	10.126	.379	.00	24958.01	48
[TSV (warm) = 3]	0[a]	.	.	.	.
Location					
PET	0.269	.011	.00	1.31	1023
Solar radiation intensity	0.001	.000	.00	1	1023
Sky view factor (SVF)					
SVF=18-26%	-.278	.354	.432	0.76	33
SVF=26-34%	-.183	.169	.276	0.83	566
SVF=34-42%	-.372	.189	.05	0.69	274
SVF=42-50%	0[a]	.	.	.	148
Time of exposure (ToE)					
Below 5 mins	-.301	.117	.010	0.74	414
Above 5 mins	0[a]	.	.		606
Length of residence in Melbourne (LoR)					
>1-3 months (1)	-.039	.198	.844	0.96	102
>3-12 months (2)	.050	.232	.828	1.05	71
>1-3 years (3)	-.203	.175	.245	0.82	140
3-10 years (4)	-.045	.155	.772	0.96	192
>10 years (5)	0a	.	.	.	500

*Note: link function: Logit, (a) this parameter is set to zero because it is redundant. Note: * only analysed for the summertime*

7.4.2 DESIGN DESCRIPTOR AND THERMAL SENSATION

Sky view factor (SVF) is the descriptor of spatial design employed to understand the role of urban design in thermal conditions and thus people's thermal judgement. As per SVF percentage, the SVF value computed for the closest centre of each sub area (Tables 5.4, 5.6 and 5.8) was assigned to each participant and regrouped as four ranges "SVF 1 (18-26%)", "SVF 2 (26-34%)", SVF 3 (34-42%)" and "SVF 4 (42-50%)". The results of OLRM conducted between TSV and SVF groups under various climate conditions showed that SVF was not statistically linked to variation of TSV (Table 7.5). However, the closeness of its P-value to the significance level of 0.05 means this variable can be included in the overall OLRM for the physical environment. Between the different levels of SVF it emerged that the probability of change in TSV in response to thermal conditions was more likely to occur in areas with SVF percentage range of 42-50%.

7.4.3 LENGTH OF RESIDENCE, TIME OF EXPOSURE AND THERMAL SENSATION

The effect of "length of residence" (LoR) in the city of Melbourne and "time of exposure" (ToE) to environmental parameters during the survey on outdoor thermal sensation was examined. These two factors were also descriptors of physical thermal adaptation in outdoor settings. The detailed discussion regarding the concept of adaptation and its impact on people's thermal perceptions is provided in Chapter 2. For accuracy of analyses and the responses' even distribution, the four choices for ToE were reclassified into two categories: firstly, of "less than 5 minutes" (N=414); and secondly, "more than five minutes" (N=606). The findings of OLRM analysis indicated that ToE is a significant determinant of users' outdoor thermal sensation over the course of the study (Table 7.5) at the 0.05 significance level; hence, it was included in the overall regression model (Table 7.6). The measure of odds ratio between the two categories of ToE demonstrated that people's TSV being exposed to thermal conditions under five minutes were less likely to change with thermal conditions (e^x=0.74). Accounting for "solar radiation", "SVF", and "ToE", the overall OLRM revealed that physical environment had a middling influence on people's thermal sensation according to Nagelkerke's classification of pseudo-R^2 (Delhey and Newton 2002) (pseudo-r^2= 54.1). Table 7.6 summarises the findings of OLRM to document the overall impact of physical environment on thermal sensation. The corresponding discussions on the findings in physical environment are presented in Chapter 8, Section 8.7.6.

Table 7.6. Summary of the overall logistic regression model for physical environment

Thermal sensation vote *Threshold*	Est.	Std. error	Sig	e^x	Pseudo-R^2
Cold= -3	1.074	.285	.00	2.93	
Cool= -2	2.703	.264	.00	14.92	
Slightly cool= -1	4.795	.284	.00	120.84	
Neutral= 0	5.893	.301	.00	362.27	
Slightly warm= +1	7.375	.331	.00	1594.37	
Warm= +2	9.995	.408	.00	21893.91	
Location					
PET	.249	.012	0.00	1.28	51.6
Solar radiation intensity	.001	.00	0.00	1	53.3
Sky view factor (SVF)					53.4
SVF=18-26%	.017	.359	.962	1.02	
SVF=26-34%	-.095	.170	.575	0.91	
SVF=34-42%	-.192	.192	.317	0.83	
SVF=42-50%	0	.	.	.	
Time of exposure					54.1
Below 5 mins	-.306	.118	.009	0.74	
Above 5 mins	0	.	.		

Note: link function: Logit, (a) this parameter is set to zero because it is redundant

7.5 PSYCHOLOGICAL ENVIRONMENT

In this environment, the modifying role of psychological in variation of TSV was investigated. Included in the psychological environment were “purpose and frequency of visit”, “overall comfort”, “thermal preference”, “weather forecasts”, “thermal history”, “thermal history”, “character of place”, “features of place”, “the level of naturalness” “seasonal change” and “perceived control”. Using aggregated data, the OLRM examined the effect of psychological factors on people’s outdoor thermal sensation.

7.5.1 PURPOSE AND FREQUENCY OF VISIT AND THERMAL SENSATION

The relationships between TSVs and the two psychological factors, i.e. “purpose of visit” (PoV) and “frequency of visit” (FoV) were examined for the period of study (Table 7.7). For the purpose of accuracy of analyses and responses even distribution, the initial five levels of “visit frequency” were re-categorised into three groups: “daily to several times a week”, “few times a week to few times a month” and “rarely to first time”. As shown in Table 7.7 almost half of the survey users (N=598) had a pattern usage of “daily to few times a day" visits. The OLRM analysis findings indicated that both PoV and FoV had an insignificant relationship with TSV variation (P>0.05).

Table 7.7. Ordinal estimates for users' thermal sensations in psychological environment

Thermal sensation vote	Est.	Std. error	Sig	e^x	N
Threshold					
[TSV (cold) = -3]	1.392	.237	.00	4.02	45
[TSV (cool) = -2]	2.994	.213	.00	19.96	102
[TSV (slightly cool) = -1]	4.997	.237	.00	147.89	262
[TSV (neutral) = .0]	6.026	.257	.00	413.80	157
[TSV (slightly warm) = 1]	7.464	.291	.00	1742.76	200
[TSV (warm) = 2]	10.126	.379	.00	24958.01	48
[TSV (warm) = 3]	0[a]	.	.	.	.
Location					
PET	.22	.013	.00	1.22	1023
Frequency of visit (FoV)					
Daily to several time a week =1	-.080	.172	.643	0.83	497
Few times a week to few times a month =2	-.143	.177	.421	0.87	379
Rarely to first time = 3	0	.	.	.	147
Purpose of visit (PoV)					
Having break/resting/change of environment					
a (chosen)	-.184	.136	.252	0.83	524
b (not-chosen)	0	.	.	.	497
Getting fresh air					
a (chosen)	.057	.138	.654	1.77	745
b (not-chosen)	0	.	.	.	276
Playing					
a (chosen)	.897	.227	.265	2.45	947
b (not-chosen)	0	.	.	.	74
Passage to another place					
a (chosen)	1.198	.162	.964	3.31	4
b (not-chosen)	0	.	.	.	790
Having lunch/snack					
a (chosen)	-.053	.144	.676	0.95	231
b (not-chosen)	0	.	.		788
Read/write					
a (chosen)	-.086	.251	.174	0.92	233
b (not-chosen)	0	.	.	.	964
Meeting/waiting for someone					
a (chosen)	.309	.173	.742	1.36	57
b (not-chosen)	0	.	.	.	886
Thermal preference					
Cooler= 1	1.102	.185	.00	3.01	211
No change= 2	.993	.145	.00	2.70	486
Warmer= 3	0	.	.	.	322
Overall comfort					
Very uncomfortable= 1	.023	.321	.942	1.02	38
Moderately uncomfortable= 2	-1.047	.253	.00	0.35	72
Slightly uncomfortable= 3	-.775	.199	.00	0.46	147
Just right= 4	-.258	.181	.154	0.77	197
Slightly comfortable= 5	-.138	.219	.528	0.87	105
Moderately comfortable= 6	-.349	.171	.041	0.71	248
Very comfortable= 7	0	.	.	.	214
Thermal history					
Indoor, non-ventilated= 1	-.315	.229	.170	0.73	98
Indoor, conditioned= 2	-.149	.156	.340	0.86	536
Outdoor, under shade= 3	-.199	.187	.289	0.82	200
Outdoor, under sun= 4	0	.	.	.	185

Character of place						
Site 1	1	.136	.012	.341	1.15	315
Site 2	2	-.277	.143	.057	0.76	366
Site 3	3	0	.147	.	.	340
Feature of place						
Plants and exposure to nature						
a (chosen)		-.104	.118	.378	0.90	429
b (not-chosen)		0			.	592
An environment with a better ambient conditions						
a(chosen)		-.250	.123	.042	0.78	689
b (not-chosen)		0			.	332
Beauty of the place compared to the other environments		.022	.120	.854	1.02	
a (chosen)		0			.	647
b (not-chosen)						374
Convenient access and closeness to my school/workplace						
a (chosen)		.075	.115	.514	1.08	534
b (not-chosen)		0	.	.	.	487
Naturalness						
Advocating/not disagreeing with more natural green spaces= 1		.067	.133	.614	1.07	763
Disagreeing more natural green spaces= 2		0	.	.	.	253
Perceived control (adaptive strategy)						
Taking an adaptive action		.103	0.132	0.43	1.11	763
none		.	.	.	.	256
Seasonal change						
Spring=	1	1.509	.200	.00	4.52	368
Summer=	2	1.325	.213	.00	3.76	413
Autumn=	3	0	.	.		240

Note: Link function: Logit, (a) this parameter is set to zero because it is redundant

7.5.2 OVERALL COMFORT, THERMAL PREFERENCE AND THERMAL SENSATION

The interaction between the two other indicators of people's thermal perception (i.e. overall comfort and thermal preference) and TSV was studied under various thermal conditions for the period of study (Table 7.7). The results of OLRM revealed that all the levels of "thermal preference" and some levels of "overall comfort" were statistically linked to variation of TSV concerning aggregated data ($P<0.05$) and therefore they were included in the overall OLRM for psychological environment. The results for the odds ratio between different levels of these two perceptual indicators suggested that people who preferred "cooler" thermal conditions ($e^x=3.01$) and perceived thermal conditions "very uncomfortable" (e^x=0.023) were more likely to change their TSVs in response to the microclimate conditions.

7.5.3 WEATHER FORECAST, THERMAL HISTORY, AND THERMAL SENSATION

The weather forecasts checked by outdoor users before leaving home alongside with their thermal history (thermal experience) was investigated. As shown in Table 7.8 the conditions of participants' thermal history were acquired using a multiple-choice question and the results were as follows: "indoor non-ventilated space" (N=98), "indoor-conditioned space" (N=536), "outdoor under shade" (N=200) and "outdoor exposed to sunlight" (N=185). The relationship between weather forecast and thermal sensations was only examined during the field survey in autumn and participants were asked if they had checked the weather forecast before attending the study site. The OLRM applied to these two factors and the outcome did indicate non-significant relationships, respectively, in the period of study and autumn (Table 7.7). Consequently, they were not incorporated into the overall regression model of psychological environment. Furthermore, in order to further understand whether weather forecast impacted on people's clothing patterns a one-way ANOVA test was run. Results indicated that there was no statistical difference in the clothing patterns of those checking weather forecasts and those who did not ($F(1, 278) = 0.92$, $P>0.05$).

7.5.4 PLACE CHARACTER, SPATIAL FEATURES, NATURALNESS AND THERMAL SENSATION

The impact of character of place, spatial features, and naturalness on thermal sensation was investigated under various climate conditions using OLRM (Table 7.7). Character of place as an overarching concept involves all relevant characteristics of an open space that can potentially influence users' attitude and, therefore, their comfort conditions. Also, the study asked the participants their views on the most attractive features of the place through the following options: "plants and exposure to nature", "an environment with a better ambient conditions", "beauty of the place compared to other environments", and "convenient access and closeness to my school/workplace". The respondents' opinions about establishing new natural green spaces was also sought, in which 75% of people advocated (did not disagree) more natural green spaces were needed. The analytical results for these three factors could not provide evidence for significant relationship between them and variation in TSV, except for the sub-factor of "an environment with better ambient conditions" (β=-0.25, $P<0.05$). This was a feature that attracted people to visit the study open spaces (Table 7.7). Nonetheless, as the P-value corresponding to place character was close to the 0.05 significance level, this factor was also included in the overall regression model. Comparing the values of odds ratio between the study sites proved that people's TSVs in Site 2 were less related to thermal conditions.

7.5.5 SEASONAL CHANGE, PERCEIVED CONTROL, AND THERMAL SENSATION

Change in thermal sensation according to season was investigated using OLRM and it was found that seasonal change could significantly affect people's thermal sensation (Table 7.7); hence, this factor was included in the OLRM developed for the psychological environment. The probability of change in TSV in response to thermal conditions was greatest in spring which is more than four times greater than that in autumn (e^x=4.52). People's perceived control over the outdoor thermal conditions was studied according to their indication to react to adverse thermal conditions. Therefore, two categories were formed: "those who took no action" (N=256) and "those who took at least one adaptive action" (N=763). Taking into consideration the factors of "seasonal change", "thermal preference", "overall comfort", and "place character" the overall OLRM of psychological environment suggested that psychological environment had little influence (5.6%) on variation of outdoor thermal sensation (Table 7.8). Furthermore, the effect of the study factors on the relationship between thermal conditions and TSV in different seasons was also investigated via separate OLRM analyses reported in Section 8.7. The corresponding discussions on the findings in psychological environment are presented in Chapter 8, Section 8.7.7.

Table 7.8. Summary of the overall logistic regression model for the psychological environment

Thermal sensation vote		Est.	Std. error	Sig	e^x	Pseudo-R^2
Location						
PET		.22	.013	.00	1.25	51.6
Seasonal change						54.6
Spring=	1	1.248	.209	.00	3.48	
Summer=	2	.946	.221	.00	2.58	
Autumn=	3	0	.	.	.	
Thermal preference						56.5
Cooler=	1	1.030	.193	.00	2.80	
No change=	2	.827	.150	.00	2.29	
Warmer=	3	0	.	.	.	
Overall comfort						57.0
Very uncomfortable=	1	.296	.333	.374	1.34	
Moderately uncomfortable=	2	-.643	.266	.015	0.53	
Slightly uncomfortable=	3	-.293	.212	.166	0.75	
Just right=	4	-.063	.188	.736	0.94	
Slightly comfortable=	5	.150	.223	.501	1.16	
Moderately comfortable=	6	-.198	.173	.254	0.82	
Very comfortable=	7	0	.	.	.	
Place character						57.2
Site 1		.130	.145	.371	1.14	
Site 2		-.142	.154	.358	0.86	
Site 3		0	.	.	0	

Note: link function: Logit, (a) this parameter is set to zero because it is redundant

7.6 POLICIES AND STANDARDS ENVIRONMENT

The focus of the fifth environment is on reviewing available standards and policies concerning thermal comfort, in order to explore their potential impact on people's thermal perceptions. There is a received wisdom that policies and standards set to regulate the human-place relationship could modify people' attitudes, perceptions and ultimately behaviours over time. Several behavioural change theorists have proposed some models signifying such a relationship between members of a society and regulations (Mowrer 1960, Jackson 2005, Etienne 2010). These models help policy-makers and planners understand the factors that encourage or enforce people to adapt to devised standards and policies leading to achieving a set of pre-defined goals.

In the context of thermal comfort, it is essential to realise that policies should not only focus on the relationship between meteorological conditions and built environments. They need to take into account people's expectations and interactions with outdoor built environments. Outdoor built environments are built for people, by people and are visited by people and therefore it is of particular importance to give weight to human dimensions. These policies and standards should be indeed concerned with human feelings, perceptions, judgment, behaviour, etc. Currently, it seems that the policies paying attention to technical details of thermal comfort including human thermoregulatory systems outweigh those concerned with people's expectations and behaviours. Furthermore, some evidence proved that in some contexts the available policies failed to induce a noticeable change in people's thermal perceptions and usage patterns in the given thermal environment. In this context, Jackson (2005) indicated that "*the sheer complexity of human behaviours and motivations makes it very hard to predict with certainty what the impacts of policy interventions on people's behaviour are going to be*" (p. 119).

In this RUCC study, reviewing the available policies and standards it was found that only a few documents about thermal conditions have been made available to the public for maintaining thermal comfort, health and well-being. These are: "Thermal Comfort Instruction V.2 (POL/2010/00572-last updated in 2014)", "Health, Safety and Security Policy (POL/2008/00165-last updated 2009)", "Roles and Responsibility for Health and Safety Instruction V.2 (POL/2010/00568-last updated in 2014" and "Health and Safety Issues Resolution Procedure V.1 (POL/2009/00010-last updated in 2013). These policies intend to provide safe environments for the users of RUCC built environments and procedures, so that action can be taken when environmental risks occur. For instance, Thermal Comfort Instruction V.2 aims to "*provide guidance for a safe and healthy environment for staff, students and visitors, to the University by addressing the issue of thermal comfort in the workplace... this instruction provides information on the identification and control of risks in thermal environments (hot or cold) where staff, contractors or students may be required to conduct work tasks or activities*" (RMIT University 2010). Comfort instruction recommended comfort thermal ranges in RUCC built environments for different seasons and advise on how people should react to risks associated with the thermal environment. Nevertheless, the focus is largely centred on indoor thermal comfort (i.e. offices, lecture rooms and other educational spaces) and when it comes to the outdoor environment, it is limited to recommending some safety measures while attending the university campus's outdoor spaces.

Another source available to students and staff is weather forecasts through which people can regulate their thermal expectations. As discussed in Section 3.4.4 checking weather forecasts proved to be an effective way to achieve thermal comfort because it is linked to both psychological and physiological thermal adaptation. However, at times the weekly forecasts were unreliable as weather conditions might not eventuate in Melbourne due to their high changeability (Pearce et al. 2011). Therefore, it is important to encourage the university students and staff to check the weather forecast daily. The empirical evidence showed that weather forecasts are the ones widely used by students and staff of RUCC when attending the study sites. Further discussions on this topic is presented in Chapter 8, Section 8.7.8.

7.7 THERMAL SENSATION AND CONTEXTUAL FACTORS: BY SEASON ANALYSIS

It is assumed that change in season may impact on the effect of contextual factors on people's thermal perceptions. Therefore, the impact of these factors was investigated in and compared in different seasons. The results of the season analysis revealed a set of interesting patterns specifying the varying modifying effect of study factors on people's thermal sensation in different seasons (Table 7.9). Overall, it emerged that while seasonal analyses for the three factors of gender, activity level, and posture revealed a similar pattern compared to those obtained for the entire period of study, others exhibited a different modifying pattern in each season. For instance, despite the results showing the meaningful effect of age, exposure, and clothing insulation on TSV using aggregated data, they had no meaningful effect, respectively, in summer to autumn and spring to summer. Furthermore, while skin colour was not an influential factor in the creation of TSV in each season, it proved to be a significant parameter throughout this study. Similar findings were derived when analysing social environment in different seasons; while the three study factors of climatic background, companionship, and position were determinants of outdoor TSV using aggregated data ($P<0.05$), they had no meaningful effect in summer, autumn; and spring to summer ($P>0.05$), respectively. Table 7.9 presents the seasonal analyses of various factors clustered under SESM environment.

Table 7.9. The ordinal estimates for users' thermal sensations in different seasons

	Season		Spring		Summer		Autumn	
	levels		Est.	Sig.	Est.	Sig.	Est.	Sig.
Location			**Individual Environment**					
Age	<18-30= 1		.484	.073	.379	.192	.630	.144
	30-45=2		.718	.015	.522	.107	1.294	.013
	>45=3		0	.	0	.	0	.
Gender	Male= 1		.000	.999	.283	.128	.220	.423
	Female= 2		0	.	0	.	0	.
Clo	Continuous		-.946	.005	-.763	.060	-.467	.337
MET	Continuous		-.057	.635	.155	.176	.114	.458
Skin	Dark=1		-.192	.388	-.355	.086	-.399	.218
	Light=2		0	.	0	.	0	.
Posture	Standing=		-1.121	.092	-.539	.090	-.020	.963
	Sitting=		-.557	.402	-.400	.212	-.346	.428
	Lying down=		0	.	0	.	0	.
Exposure	In sunny spot = 1		.622	.002	.835	.000	.033	.950
	Under shade =2		0	.	0	.	0	.
			Social Environment					
Companionship	Along=1		-.481	.013	-.439	.016	.305	.205
	Accompanied= 2		0	.	0	.	0	.
Position	Academic=1		.016	.939	-.167	.538	-.773	.048
	Non-academic=2		0	.	0	.	0	.
Climatic background	Tropical= 1		-1.683	.000	-.647	.246	-1.325	.078
	Dry=2		-1.739	.000	-.090	.877	-1.886	.034
	Temperate=3		-1.024	.005	.082	.875	-1.002	.163
	Cold=4		0	.	0	.	0	.
			Physical Environment					
PET	Continuous		.202	.00	.237	.019	.287	.00
SVF	SVF=18-26%=	1	-.272	.668	-.276	.611	.647	.402
	SVF=26-34%=	2	-.422	.101	-.151	.626	.388	.310
	SVF=34-42%=	3	-1.062	.00	.148	.684	.907	.029
	SVF=42-50%=	4	0	.	0	.	0	.
LoR	>1-3 months=	1	1.053	.030	-.986	.007	.718	.449
	>3-12 months=	2	-.879	.009	-.321	.449	.746	.094
	>1-3 years=	3	-.106	.770	.578	.252	.253	.706
	3-10 years=	4	-.465	.046	-.168	.487	.358	.226
	>10 years=	5	0	.	0	.	0	.
ToE	Below 5 mins		-.364	.064	-.226	.222	.703	-.092
	Above 5 mins		0	.	0	.	.	0

Frequency of visit	Daily to several time a week =	1	.028	.920	-.325	.228	-.201	.387
	Few times a week to few							
	times a month=	2	.166	.574	-.368	.194	-.269	.254
	Rarely to first time=	3	0	.	0	.	0	.
	Psychological Environment							
purpose of visit	Having break/resting/change of							
	environment		-.450	.051	-.228	.303	.094	.738
	a (chosen)		0	.	0	.	0	.
	b (not-chosen)							
	Getting fresh air		-.037	.867	.247	.268	-.324	.278
	a (chosen)		0	.	0	.	0	.
	b (not-chosen)							
	Playing		-1.304	.029	-.259	.421	-.308	.449
	a (chosen)		0	.	0	.	0	.
	b (not-chosen)							
	Passage to another place		.032	.911	-.155	.551	-.394	.230
	a (chosen)		0	.	0	.	0	.
	b (not-chosen)							
	Having lunch/snack		-.165	.518	-.139	.536	.119	.703
	a (chosen)		0	.	0	.	0	.
	b (not-chosen)						-.187	
	Read/write		-.174	.707	.564	.178	0	.681
	a (chosen)		0	.	0	.		.
	b (not-chosen)						-.017	
	Meeting/waiting for someone		-.237	.468	.072	.789	0	.958
	a (chosen)		0	.	0	.		.
	b (not-chosen)							
Place feature	Plants and exposure to nature							
	a (chosen)		-.360	.066	.022	.907	.166	.502
	b (not-chosen)		0	.	0	.	0	.
	An environment with a better ambient conditions							
	a(chosen)		-.093	.651	-.436	.025	-.327	.200
	b (not-chosen)		0	.	0	.	0	.
	Beauty of the place compared to the other environments							
	a (chosen)		-.315	.110	.102	.593	.330	.199
	b (not-chosen)		0	.	0	.	0	.
	Convenient access and closeness to my school/workplace							
	a (chosen)		.149	.438	-.038	.836	-.074	.762
	b (not-chosen)		0	.	0	.	0	.
Thermal preference	Cooler=	1	1.655	.00	.241	.428	1.930	.023
	No change=	2	1.560	.00	.047	.870	.481	.074
	Warmer=	3	0	.	0	.	0	.
Overall comfort	Very uncomfortable=	1	n/a	n/a	.640	.117	-.170	.833
	Moderately uncomfortable=	2	.597	.526	.531	.168	-2.032	.001
	Slightly uncomfortable=	3	-.697	.072	.059	.858	-.725	.162
	Just right=	4	-.291	.328	.129	.668	.209	.691
	Slightly comfortable=	5	-.404	.230	.479	.204	.313	.587
	Moderately comfortable=	6	-.292	.209	-.090	.767	.053	.920
	Very comfortable=	7	0	.	0	.	0	.
Thermal history	Indoor, non-ventilated=	1	-.308	.374	-.387	.330	-.218	.658
	Indoor, conditioned=	2	-.086	.726	-.066	.786	-.108	.771
	Outdoor, under shade=	3	-.013	.969	.005	.986	-.107	.785
	Outdoor, under sun=	4	0	.	0	.	0	.
Perceived control	Taking an adaptive action	1	.33	0.175	0.404	.047	-0.854	.02
	None	2	0	.	0	.	.	.

Naturalness	Advocating more natural green spaces= 1	.218	.334	.260	.198	-.317	.266
	Disagreeing more natural green spaces= 2	0	.	0	.	0	.

Regarding the physical environment and weather conditions (PET), the survey population in autumn was more affected by thermal conditions (ß=0.28, P<0.01) than in summer (ß=0.23, P<0.05) and spring conditions (ß=0.20, P<0.01). While not significantly interacting with thermal sensation in summer, SVF showed significant but positive and negative relationships with TSV in spring and autumn, respectively. Comparing these two later seasons, people's TSV within the third level of SVF (34-42%) was found to be more influenced in spring (ß=-1.06, P<0.01) than in autumn (ß=0.97, P<0.05). LoR was not a determinant factor when the aggregated data was used, however, in the inter-seasonal analyses it did have a statistically significant relationship with peoples' TSVs in spring (ß=1.05, P<0.05) and summer (ß=-0.98, P<0.01), with a roughly similar weight of effect within the first level (>1-3 months of residence). Unlike in the aggregated data, ToE status in each season was not a meaningful modifier of TSV variation in each season (P>0.05). The results of by-season analysis for FoV, thermal history and the level of naturalness resembled the findings from their aggregated data and had no statistically significant influence. As per PoV while the findings on aggregated data had failed to demonstrate any meaningful relationship, "playing" in spring was found to be a determinant of TSV (ß=-0.89, P<0.05) (Table 7.9). Except for "an environment with better ambient conditions" in summer (ß=-0.43, P<0.05) which was also found to be influential factor within the aggregated data previously (ß=-0.25, P<0.05) none of the other choices for place features had a statistical relationship with TSV.

By-season analysis also applied to people's seasonal thermal votes (i.e. thermal preference and overall comfort) to understand whether the defined relationship in aggregated data existed in different seasons. Interestingly, the results showed the study relationship was not similar in various seasons (Table 7.9). Having no impact on thermal sensation in summer (P>0.05), thermal preference and overall comfort contributed to variation of TSV in autumn. In spring, only thermal preference was found to be a determinant of thermal sensation. The findings also suggested that people's thermal preference was more effective on thermal sensation in autumn (P<0.05, ß=1.93) than in springtime (P<0.01, ß=1.65). Perceived control in the form of taking or not taking adaptive action in response to adverse thermal conditions had a meaningful relationship with TSV in summer (P<0.05) and autumn (P<0.01). Conversely, the analysis for the aggregated data and spring demonstrated insignificant interaction with peoples' thermal sensation votes (P>0.05). The corresponding discussions are presented in Section 8.7.3.4.

7.8 IMPACT OF TOTAL CONTEXTUAL FACTORS ON THERMAL SENSATION

Those factors identified to be in a statistical significant relationship with people's TSV during the study period were included in the final OLRM. Here the objective was to understand the overall impact of the study contextual factors in varied thermal sensations. In total, 11 factors along with the PET values took the shape of the model in which the prediction of thermal sensation in outdoor environments could be done accurately; it was 59.40% (Table 7.10). Among the study factors, individual and physical parameters were found to make the most contributions to the final OLRM. The results of the final model suggested that the factors of "time spent outdoor" and "skin colour" have no meaningful relationship with TSV variation in the presence of other factors. Table 7.10 provides statistical information regarding the final OLRM for the aggregated data.

Table 7.10. Summary of overall ordinal logistic regression for four SESM environments

Threshold	Estimate	Std. Error	Sig.	N
TSV = -3	-.314	.493	.525	45
TSV = -2	1.514	.479	.002	102
TSV = -1	3.959	.490	.000	262
TSV = 0	5.154	.498	.000	157
TSV = 1	6.650	.513	.000	200
TSV = 2	9.207	.560	.000	48
TSV = -3	0[a]	.	.	45
Location				
PET	.216	.014	.000	1023
SR	.000	.000	.253	1023
Clo	-.670	.234	.004	1023
Time spent outdoor				
≤5 mins	-.124	.125	.319	414
>5 mins	0[a]	.	.	606
Exposure to sun				
In sunny spot = 1	.515	.185	.005	378
Under shade =2	0[a]	.	.	644
Age group				
<18-30= 1	.436	.193	.024	647
30-45=2	.746	.208	.000	246
>45=3	0[a]	.	.	128

Climatic background				
Tropical=1	-1.034	.410	.012	182
Dry=2	-1.169	.306	.000	96
Temperate=3	-1.132	.334	.001	652
Cold=4	-.651	.280	.020	49
Tropical=1	0^a	.	.	182
Companionship				
Alone= 1	-.247	.124	.047	523
Two people or more= 2	0^a	.	.	500
Sky view factor				
18-25=1	.038	.365	.011	33
25.1-32=2	-.085	.178	.230	566
32.1-39=3	-.068	.198	.117	274
39.1-46=4	0^a	.	.	148
Change in season				
Spring= 1	1.195	.221	.000	368
Summer= 2	1.043	.233	.000	413
Autumn= 3	0^a	.	.	242
Skin colour				
Dark=1	-.187	.152	.220	234
Light=2	0^a	.	.	789
Overall comfort				
Very uncomfortable =1.0	.211	.337	.530	38
Moderately comfortable =2.0	-.739	.269	.006	72
Slightly comfortable =3.0	-.383	.212	.070	148
Just right =4.0	-.077	.192	.688	197
Slightly comfortable=5.0	.010	.227	.965	106
Moderately comfortable =6.0	-.183	.175	.297	248
Very comfortable =7.0	0^a	.	.	214

Understanding the relationship between people's thermal sensation (outcome variable) and different contextual factors (predictor variables), the study discovered the pattern of change in coefficient of determination when adding the statistically significant influential factors into the final model. The results of the final model showed a 7.8% rise in the coefficient of determination, which also indicates the OLRM model's ability to predict people's thermal sensation in outdoor spaces. In the statistical sciences, this small increase in the percentage of pseudo-R^2 is still considered to be notably influential; as indicated before its variation does not equal that in the normal regression R^2. The rise in the coefficient of determination also is indicative of the impact of contextual factors on people's thermal sensation, which addresses the second research question. The discussion on this finding is presented in Chapter 8, Section 8.7.3. Table 7.11 documented the track of changes in the coefficient of determination in the final OLRM.

Table 7.11. Summary of the overall logistic regression model for four SESM environments

Parameters	*pseudo-R^2* (%)
PET	51.60
PET+ age	52.30
PET+ age + Clo	53.40
PET+ age + Clo+ exposure to sun	54.90
PET+ age + Clo+ exposure to sun+ skin colour	55.10
PET+ age + Clo+ exposure to sun+ skin colour+ climatic background	56.30
PET+ age + Clo+ exposure to sun+ skin colour+ climatic background+ companionship	56.50
PET+ age + Clo+ exposure to sun+ skin colour+ climatic background + companionship + SR	56.80
PET+ age + Clo+ exposure to sun+ skin colour+ climatic background + companionship + SR+ time spent outdoor	57.30
PET+ age + Clo+ exposure to sun+ skin colour+ climatic background + companionship + SR+ spent outdoor+ seasonal change in season	58.90
PET+ age + Clo+ exposure to sun+ skin colour+ climatic background + companionship + SR+ spent outdoor + seasonal change + overall comfort	59.40

To check the goodness of fit or the quality of the adjustment of ordinal models, a Deviance test was conducted for the models run for each environment and the combination of environments. This analytical test is part of the report output generated following the logistic ordinal regression analysis. Accordingly, the chi-square of Deviance served to interpret the goodness of fit, and any value greater than 0.05 signifies a proper goodness of fit. As tabulated in Table 7.12, Deviance measure confirmed the satisfactory goodness of fit for models tested for each environment and total environments. Therefore, the model is found to generate accurate results that identified the predictors of variations in thermal sensation.

Table 7.12. The goodness of fit for overall regression model of the study SESM environments.

Environment	Chi-square	df	Sig
Individual	2744.42	5742	1
Social	2206.78	4169	1
Physical	2691.30	5442	1
Psychological	2698.97	5664	1
All environments	2744.52	6018	1

7.9 THERMAL ADAPTATION

Thermal adaptations among the user of RUCC open spaces were evident through three forms of adaptation (i.e. physical, psychological, and behavioural). In the physical environment, ToE and LoR (in spring and summer) along with “climatic background” in social environment were the indicators of physiological thermal adaptation. The former (physical) and latter (behavioural) occurred throughout the year (Table 7.5) and the middle one (psychological) was only evident in summer and spring (Table 7.9), suggesting a short and long-term acclimatization to local thermal conditions, respectively. The evidence for psychological thermal adaptation was proved by matching the findings with some concepts of psychological adaptation introduced by Nikolopoulou and Steemers (2003) including thermal expectation, environmental stimulation and time of exposure. Seasonal change, overall comfort, and thermal preference influenced thermal expectations throughout the year and therefore are linked to "thermal expectations" (Table 7.8). One indicator of spatial feature (i.e. an ambient with better environment) in summertime relates to environmental stimulation, and ToE is associated with the psychological concept of "time of exposure" despite its inclusion under physical environment in this study (Table 7.5). Also, varying seasonal T_n indicated thermal adaptation in relation to seasonal outdoor thermal environment; these temperature values were also largely different from those reported in studies conducted in various climate conditions (Mahmoud 2011, Yahia and Johansson 2013, Salata et al. 2016, Kántor et al. 2016). They verify the existence of the study population acclimatizing to the local climate.

The proof of behavioural adaptation (adjustment) was attributed to clothing insulation pattern over the study period. Participants' mean clothing insulation for all the aggregate data was studied within the 2 ˚C PET interval using the second-degree polynomial regression. Results showed that clothing value is a function of the outdoor thermal conditions with a strong coefficient of determination (R^2=0.91). Nevertheless, as shown in Figure 7.2, when the PET values in the survey increased, users tended to reduce their clothing to a certain point at which with increase in PET they then added to their clothing. This increase probably referred to the behavioural adjustment were people tried to protect their skin from increasing solar radiation.

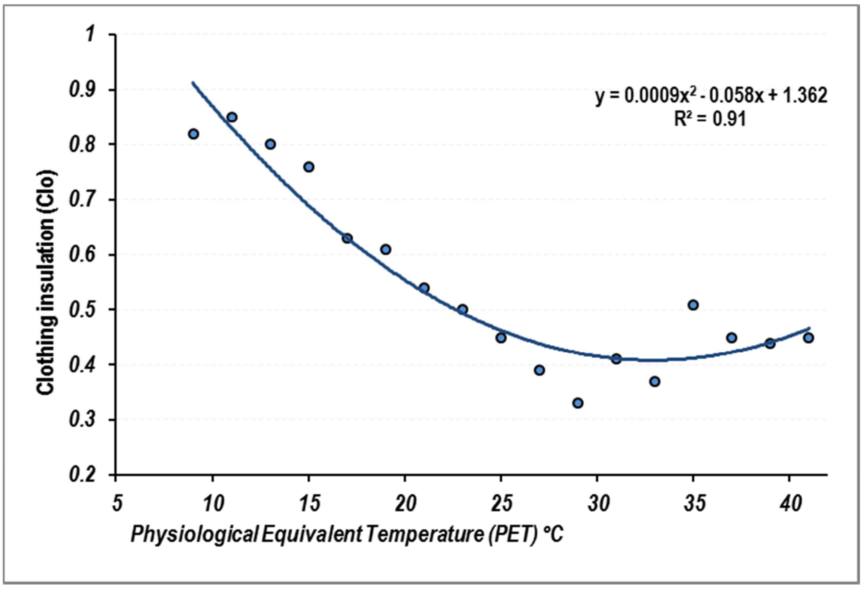


Figure 7.2. Mean clothing insulation values of RUCC users during study period

Furthermore, to understand how the users of outdoor spaces may consider adaptive adjustments, participants were asked to indicate the measure(s) they may take in response to current weather conditions (Table 7.13). Users had five choices to choose from: "use umbrella/hat", "move to shade /sunlight", "reduce/add clothing", "no change", and "others". As tabulated below, in total "move to shade or sunlight" (37.5%), and "reduce or add clothing" (31.5%) were the most common adaptive actions employed to cope with undesirable thermal conditions. Additionally, the seasonal change was found to govern how these actions were prioritised. Comparing autumn and summer conditions, it was understood that "adding to clothing insulation" (44.8%) and "move to shade" (45.5%) were the typical adaptive strategies, respectively, in the former and latter. Results showed that outdoor users did not favour using personal accessories including umbrella and hat, which may provide protection against the sun and wind throughout the year. Table 7.13 illustrates the frequency distribution of choices (percentage) of the adaptive measures that participants indicated in field surveys.

Table 7.13. Users' Adaptive behaviour in response to the current weather conditions.

Adaptive behaviour	Spring (%)	Summer (%)	Autumn (%)	Combined (%)
Use umbrella/hat	10.7	9.2	4.2	8.5
Move to shade /sunlight	37.1	45.2	25.2	37.5
Reduce/add clothing	34.7	20.8	44.8	31.5
No change	15.4	24.0	24.1	20.9
Others (please specify)	2.1	0.8	1.7	1.5

7.10 SUMMARY

This chapter investigated the modifying effects of contextual factors, clustered under the SESM environments, on outdoor thermal sensations. Results showed that from 28 contextual factors only 13 wielded a statistically significant influence on thermal sensations in RUCC open spaces. Using aggregated data and TSV as an indicator of thermal response, this study proved that “users’ age”, “skin colour”, “clothing insulation”, and their “level of exposure to sun” did meaningfully influence thermal sensation in individual environment. In social environment, “companionship”, “position”, and “climatic background” modified the relationship between TSV and thermal conditions. Statistically significant factors in physical environment were the collective effect of four environmental parameters (i.e. RH, Ta, T_g and Va), “intensity of solar radiation”, “sky view factor”, and “length of stay outdoor”. The analytical results in psychological environment demonstrated that from the ten factors studied, only “seasonal change”, “overall comfort”, and thermal preference had a significant influence on variation of outdoor TSV. Taking these factors into the final ordinal logistic regression model, this study suggested an approx. 7.8% improvement in predicting thermal comfort in outdoor spaces (Table 7.11). Furthermore, the findings of by-season analysis demonstrated that these modifying effects may change with season and they could even influence TSVs in the opposite direction in different seasons (Table 7.9).

The last environment of the SESM model is concerned with the influence of available policies and standards on people’s thermal perception in the RUCC open spaces. The results showed that in the absence of standards on outdoor thermal comfort and because of unpredictability of outdoor meteorological conditions in Melbourne and less control over environmental parameters, the available comfort standards and guidelines devised for indoor conditions are unsuitable for outdoor conditions. Therefore, they are not effective in providing information that may influence people’ thermal perceptions. This finding also highlights the urgent need to create policies and standards whereby people’s thermal expectations change in favour of longer and more frequent visits to outdoor environments.

The research findings also provided evidence for thermal adaptation among outdoor users of RUCC open spaces. The change in clothing pattern worn with thermal conditions was indicative of behavioural adjustment (adaptation). Similarly, the results pertaining to "climatic background", "LoR" and "ToE" are proof of physical adaptation to local microclimate conditions. The findings also suggested the occurrence of psychological adaptation regarding "thermal expectations", "environmental stimulation", "perceived control" and "time of exposure" that are the principle mechanisms in human thermo-psychological adaptation. These principles are attributed to the contextual factors of people's "thermal preference", the sub-factor of "an environment with better ambient conditions" and taking "adaptive measure". The next chapter presents the discussions of findings from Chapters 6 and 7.

CHAPTER 8: DISCUSSION

8.1 INTRODUCTION

In the last two chapters (Chapters 6 and 7) the analytical results of field surveys and observations were presented. These results contributed to achieving the research objectives. Subsequently, this chapter presents the evaluative discussions about the findings and explores their implications for people's thermal perceptions. The research hypothesis "*existing thermal comfort standards are not adequate to assess the determinants of outdoor thermal comfort conditions*" is investigated here. Discussions on the applicability of assumptions enshrined in the available standards including ANSI/ASHRAE Standard 55 (Thermal Environmental Conditions for Human Occupancy) and BS EN ISO 7730 (Ergonomics of the Thermal Environment) examine the hypothesis by providing evidence on the disparities found between these assumptions and research findings. Above all, the development of an argument around these disparities helps to address the first research question (*to what extent are the thermal comfort standards applicable to educational urban precincts in the context of Australian cities?*). Such disparities are further reviewed and explained by a theoretical framework consisting of three theories/models (i.e. SESM model, alliesthesia and rising expectations). The theoretical framework assists in justifying the origin and context-specific reasons for discrepancies found between the results and the conventions well established in comfort standards. Furthermore, the discussions developed corresponding to the findings presented in Chapter 7, address the second research question (*to what extent can contextual factors influence outdoor users' thermal perceptions?*). The third research question (*what are the factors influencing usage pattern and behaviour in educational outdoor?*) is also addressed and discussed using the findings on people's usage patterns, drivers, and barriers thereof. Overall, this chapter aims to establish and further explain the pattern of outdoor users' thermal perceptions and usage of RUCC open spaces.

8.2 URBAN MICROCLIMATE AND THERMAL COMFORT

The conditions of urban climate were assessed using the measurements from three sources: BOM's synoptic weather station, on-site stationary measuring system and mobile min-weather station. The results showed that in summer (February 2015) Melbourne's CBD experienced adverse meteorological conditions where the highest records of solar exposure coincided with the high RH and T_a (see Section 6.4.1). These conditions brought thermal discomfort to the visitors and caused them to experience thermal stress. The results also indicated that RH percentage was high (around 63%) during the study summer (Table 6.2); it can theoretically impact on the cooling process via sweating. Generally high RH values weaken the efficiency of sweating in warm conditions (Berglund 1998); however, the occurrence of winds the minimum speed of 1.5 $m.s^{-1}$ (Table 6.4) during this period could improve the situation particularly in spaces that are partially blocked. This fact is also apparent in the thermal comfort predictions made for the study sites (Figure 6.23); for instance, in Site 3 where there exist limited obstacles against wind gusts, thermally discomfort conditions were shorter compared to that in the other sites. The use of wind gusts to ameliorate the hot and humid summer conditions in Melbourne's CBD was also recommended in a report in which the wind comfort criteria for this area is specified (GWTS 2016).

The measurements of meteorological conditions revealed various pattern in different seasons. In spring and summer, the radiation caused by solar exposure with high magnitudes in RUCC proved the necessity of people using sun protection methods because they were subject to direct sunlight during the day (Table 6.4). A climate change risk assessment report prepared for RUCC recommends the utilisation of shading providers including on- and above-ground green spaces to prevent outdoor users from thermally stressing sunlight (Scott et al. 2012). In autumn (May 2015), the thermal conditions inflicted a great thermal discomfort leading to slight and moderate cold stress to RUCC visitors according to thermal comfort predictions (Figure 6.23), and these conditions included the low range of T_a and solar exposure intensified by strong winds. Hence, the results indicate the need to offer warmer outdoors conditions to site users during this season. Warm conditions can be provided by installing temporary wind shelters and urban heaters when users often attend the sites.

By-site analysis of overall thermal conditions measured in the study sites displayed similarities in various seasons (Figure 6.4). The observed slight differences could be related to their specific design. For instance, the slightly higher T_a captured in Site 1 could be related to its urban form, as it dictated comparatively the higher level of wind blockage, lower surrounding buildings, and higher percentage of SVF (Table 5.3). On the other hand, the existence of water features in Site 1 was found to impose no significant change on meteorological conditions (T_a and RH), therefore it can be argued that those features were insufficient to create thermally comfortable spaces within the scale used in RUCC.

8.3 THERMAL RELATED HEALTH AND SAFETY CONSIDERATIONS IN OUTDOOR SPACES

The effects of thermal stress (imposed by cold or hot weather) on human health, wellbeing and performance have got the attention of urban researchers, planners, and urban authorities. Since three decades ago efforts have been made to raise awareness on the challenges that urban residents would encounter: climate change, population growth, urbanisation and incidents of prolonged abnormal meteorological conditions in urban areas (Oke 1982, Wilmers 1988). Over time, research embraced the concept of thermal comfort and thus thermal comfort standards and guidelines developed to evaluate the impact of thermal conditions on human health and wellbeing. In the light of research findings on the conditions of human thermal comfort, these guidelines specify the thresholds that are beyond human thermal comfort zones. In some parts of the world these guidelines were embedded in the master plans of health and safety (HaSPA 2012).

This study aimed to shed light on the requirements of human thermal comfort in urban education precincts. Education precincts including campuses are places for studying, commuting, learning, taking rest, meeting, studying, socialising, and exercising different physical activities. The results of this study showed that there were extreme cold and heat stressing incidents occurring throughout the year in RUCC open spaces (Figure 6.23). These may threaten users' health and safety as well as compromise workplace performance. In one RUCC climate change risk assessment report (Scott et al 2012) it was stated that "*...from the analysis, RUCC can be considered as moderately vulnerable to current extreme heat events (or heatwaves) and heavy rain events. Exposure to these climatic hazards has produced a range of direct and cascading impacts, some of which are* *under RMIT University's control, and some of which are not*" (p. 5). The information emerging from this study regarding the boundaries of thermal comfort (Section 6.13) can serve to create an effective guideline that informs outdoor space designers, developer, managers, and others about health and safety considerations.

8.4 COMPARATIVE EVALUATION OF THERMAL RESPONSES

This study employed four scales to understand people's outdoor thermal perceptions. As indicated before, each of these scales do sometimes contradict each other. Hence, it is important to have a clear vision about their relationship and more importantly how thermal satisfaction that conforms to the real-world conditions is defined in the study open spaces. Presented below are the discussions on the comparative evaluation of three of these scales (thermal preference, acceptance, and sensation) and their derivatives (preferred temperature, neutral temperature, and acceptable thermal range). These evaluations help to understand the applicability of thermal neutrality that is the main focus of thermal comfort standards (ASHRAE 55, ISO 7730 and CEN/EN 15251) and will lead to test the research hypothesis.

8.4.1 DETERMINATION OF THERMAL SATISFACTION BY DIFFERENT SCALES

From the four scales served to understand thermal acceptability or satisfaction, thermal acceptance is the direct measure of thermal acceptability and the other three are the indirect measures. Assuming there is a direct relationship between thermal satisfaction and TSV scale, is the most common way to project thermal satisfaction with the given thermal conditions. As indicated before, this method is concerned with the corresponding three central categories of TSV scale to thermal satisfaction and forms the foundation of the existing thermal comfort standards. With this in mind the results indicated that only about 60% of participants were satisfied with outdoor thermal conditions through the study period (Table 6.11). The distribution percentages for the seasonal data sets were 64.4%, 63.2%, and 49.6% in spring, summer, and autumn, respectively. Assuming the category of "no change" in the thermal preference scale synonymous with thermal satisfaction is the second way to characterise thermal statistician; accordingly, the results indicated that thermal satisfaction was 52.6% with seasonal percentages of 54.9%, 51.3%, and 30.6% in spring, summer, and autumn, respectively (Table 6.12). In general, for the aggregated data the results obtained from TSV represented a higher percentage of thermal satisfaction (7.4%) relative to the findings from thermal preference. This difference was even higher in the study seasons falling within 8.5%, 11.9%, and 19% of TSV central categories obtained in spring, summer, and autumn, respectively. In this regard and to better understand the interpretation of the responses obtained from these two scales, their interaction was studied by applying a cross-tabulation of the responses on them. As shown in Figure 8.1, Figure 8.2, and Figure 8.3 the votes for "no change" were mostly concentrated in the categories of "slightly warm" (+1) and "warm" (+2), resembling how people's thermal sensation votes were distributed (Figure 6.14). In autumn, however, this trend was quite different as most votes requiring "no change" were biased toward the cooler side of the TSV scale.

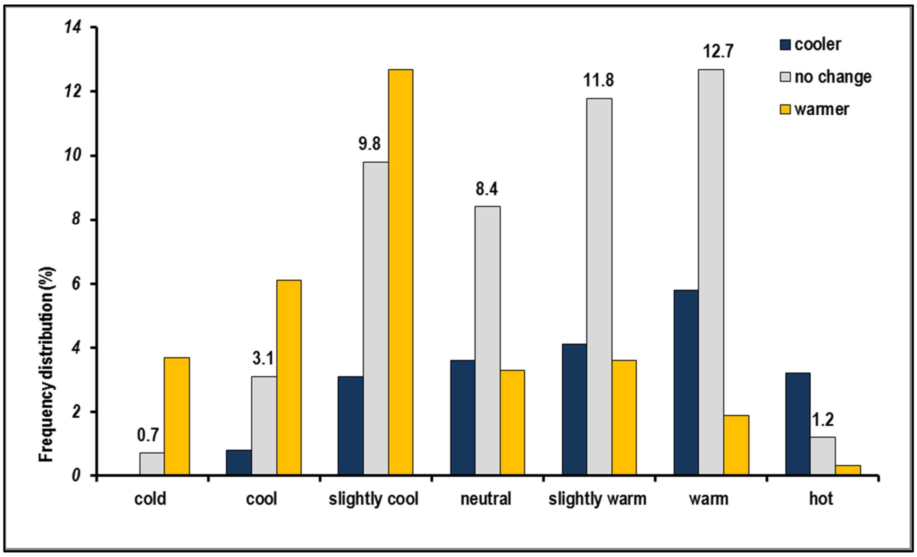


Figure 8.1. Cross-tabulation of the combined thermal preference votes versus thermal sensation categories

For the combined votes, the responses on "no change" pointed to a bias to the warmer than neutral with most of the votes cast for the categories of "slightly warm" (11.8%) and "warm" (12.7%). This trend was also found in spring (Figure 8.2) and summer votes (Figure 8.3) and reflects a similar central tendency of thermal responses in the thermal sensation scale. From the total percentage of "no change" (47.7%) responses, 32.9% was voted when participants perceived thermal conditions as "warmer than neutral" (+1, +2) and "neutral conditions" (0). The percentage resembles that obtained from the three TSV central categories (30%). However, by-season analysis revealed different ratios in the study seasons. In the warm seasons (Figure 8.2 and Figure 8.3) about half of responses indicated a preference for "no change" in thermal conditions with, respectively, 55.2% and 51.5% in spring and summer. Like the aggregated votes, in both seasons a noticeable number of users who perceived thermal conditions warmer than neutral preferred "no change" in the given thermal conditions. In the spring and summer votes, of 55.2% and 51.5% total "no change" responses, the distribution percentage at two categories of warmer than neutral (+1, +2) and the neutral category (0) was, respectively, 43.4% and 39%. This was comparable to 34.1% and 23.8% of responses in the central three categories (Figures 8.2 and 8.3).

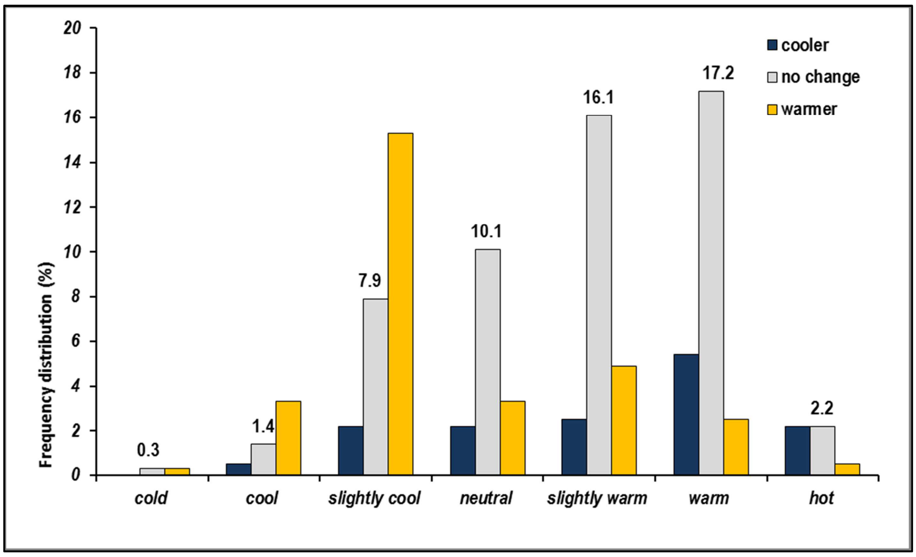


Figure 8.2. Cross-tabulation of the thermal preference votes versus thermal sensation categories in spring

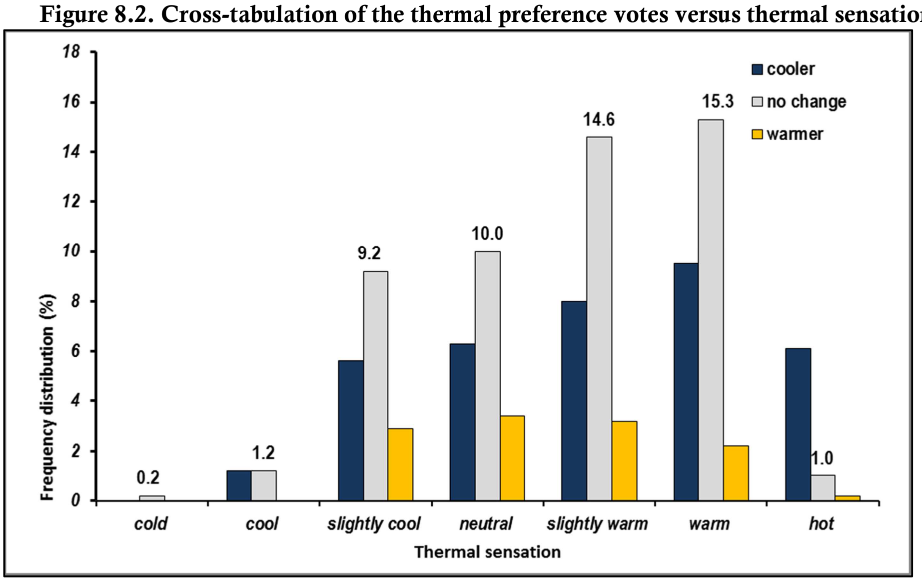


Figure 8.3. Cross-tabulation of the thermal preference votes versus thermal sensation categories in summer

In the cold season, while most of the responses were skewed towards the cooler than neutral side of the scale (-3, -2, -1) (87.5%) a desire for no change was found to be 25.1% following the desire for warmer conditions with more than 67% (Figure 8.4). In comparison to the warm seasons where the "no change" category almost received the highest percentage in all categories of thermal sensation, in autumn with one exception (warm category), people required higher temperature in all ASHRAE scale categories. For this reason, it is difficult to compare the proportion of "no change" votes between the three central categories of TSV with those on the cooler side of the thermal sensation scale (Figure 8.4). In autumn, from the total of 30.1% for "no change", 26.3% of the votes centred on cooler categories of slightly cool (-1) and cool (-2) and the neutral category (0) compared to 17.5% of the central three categories (Figure 8.4).

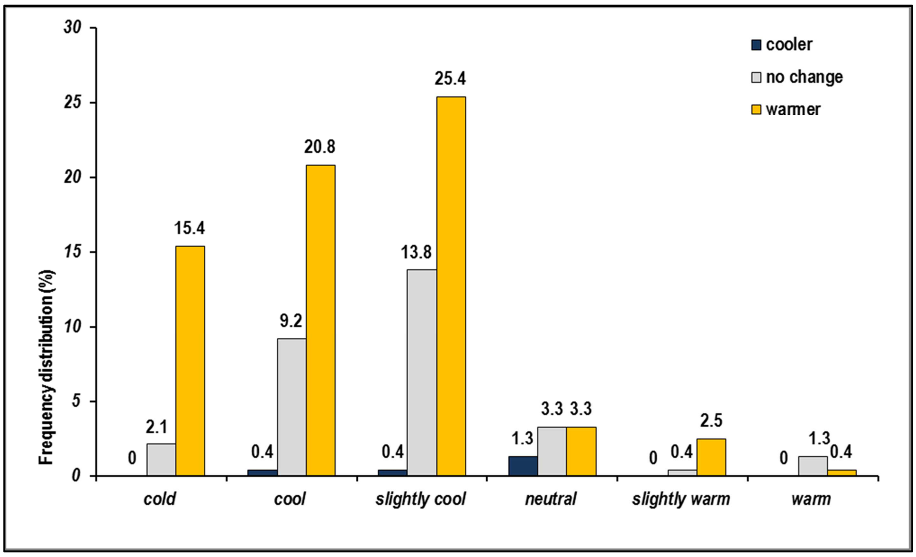


Figure 8.4. Cross-tabulation of the thermal preference votes versus thermal sensation categories in autumn

The pattern of seasonal votes on direct acceptability of thermal conditions on thermal sensation scale also indicated this biased pattern toward the warmer side of the thermal sensation scale in summer (Figure 8.7) and the cooler side in the cold season (Figure 8.8). This skewness indicates a similar shift in the central tendency to warmer categories in summer and cooler categories in autumn. The cross-tabulations of direct thermal acceptance votes versus TSV are depicted in Figures 8.6 to 8.8. For the combined votes, the distribution of the direct thermal acceptance on the warmer categories (+1, +2) and neutral category (0) was (53%) slightly lower than the three central categories (57.4%). Fountain et al. (1996) also observed this pattern in indoor thermal conditions. They argued that "*people's preferences for non-neutral (warm or* *cool) thermal sensations are common, vary asymmetrically around neutrality and in several cases are influenced by season*" (p. 181).

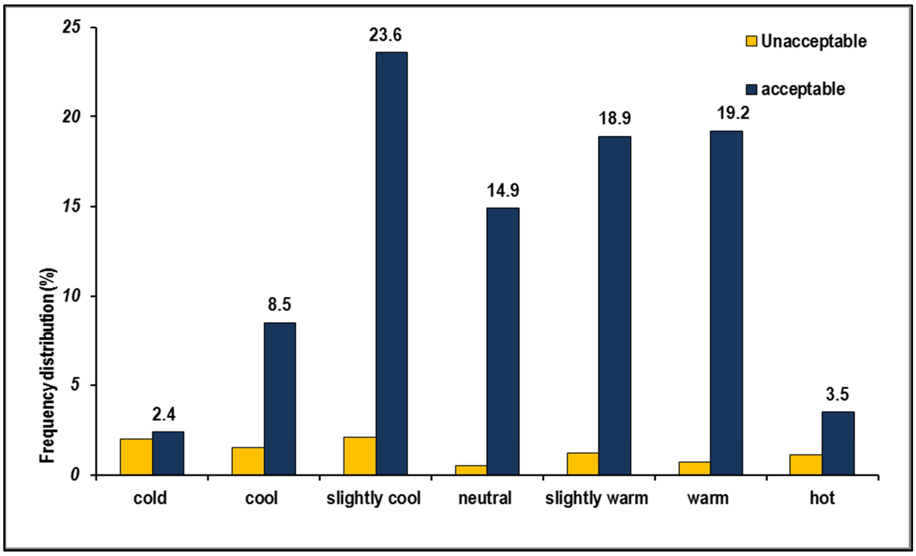


Figure 8.5. Cross-tabulation of the combined direct acceptability votes versus thermal sensation categories.

Like aggregated votes, the direct acceptance votes in spring had roughly the same percentage when the two warm categories of "slightly warm", "warm", together with "neutral conditions" (63.1%) are compared to the three central categories (62.3%). In summer, however, the proportion of the former (67.5%) was higher than the latter (59.2%). This finding suggests that direct acceptability votes were skewed toward the warmer side of the ASHRAE sensation scale. They represent the shift in central tendency from three central categories to the warmer side of the scale (Figure 8.7). This shift in the central tendency was also apparent in the cold season, where 69.8% of acceptable votes centred on the cooler categories (-1, -2) and neutral category (0) compared to that of three central categories (12.1%).

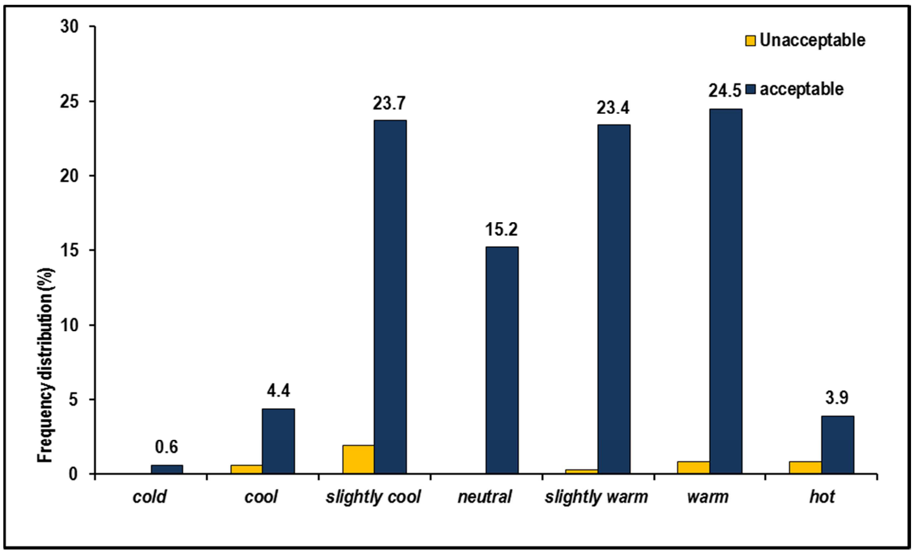


Figure 8.6. Cross-tabulation of the direct acceptability votes versus thermal sensation categories in spring

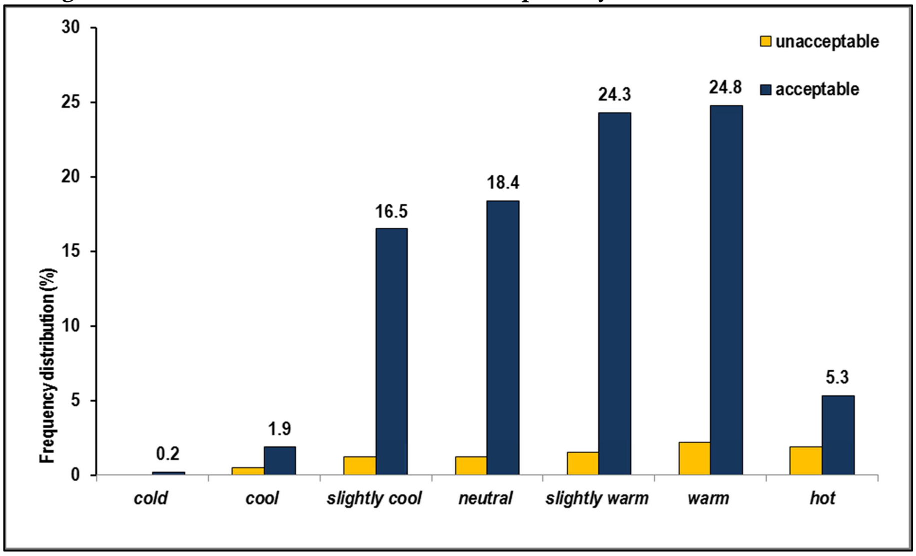


Figure 8.7. Cross-tabulation of the direct acceptability votes versus thermal sensation categories in summer

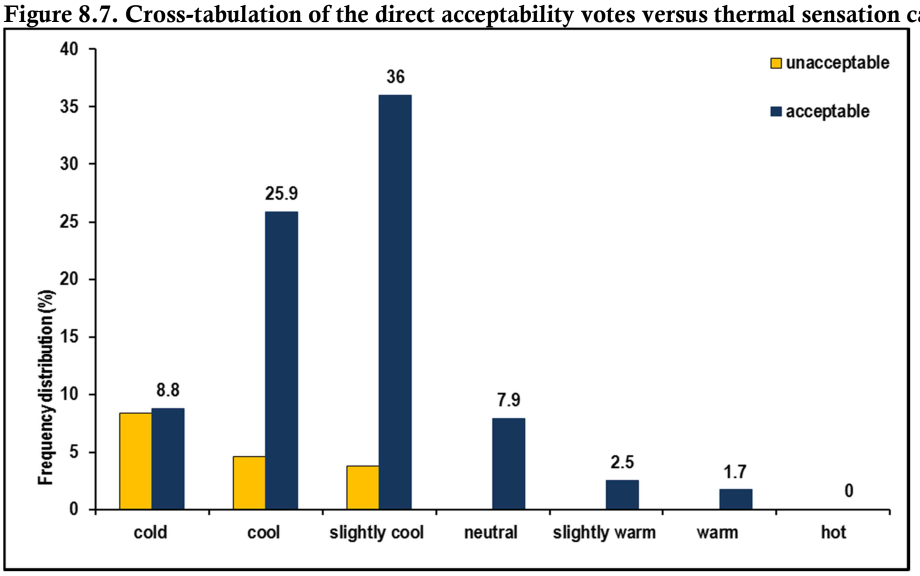


Figure 8.8. Cross-tabulation of the direct acceptability votes versus thermal sensation categories in autumn

The third indirect measure of thermal satisfaction is overall comfort. In the 7-point overall comfort scale the categories of “just right”, “slightly comfortable”, “moderately comfortable”, “very comfortable” represent thermal acceptability or satisfaction. For analysis purposes, any thermal vote from the above range was regarded as thermal satisfaction (comfortable) and beyond that was thermal dissatisfaction (uncomfortable). In the RUCC study, the cross-tabulation of overall comfort categories versus thermal sensation groups yielded a similar pattern of distribution of thermal votes. As shown in Figures 8.9 to 8.12 the shift in central tendency from the three central categories to the warmer side of scale occurred in summer and to the cooler side of the scale in autumn. For the combined overall comfort votes, the three central categories were slightly higher (49.6%) than the warmer categories (+1, +2) and neutral category (0) with 46%.

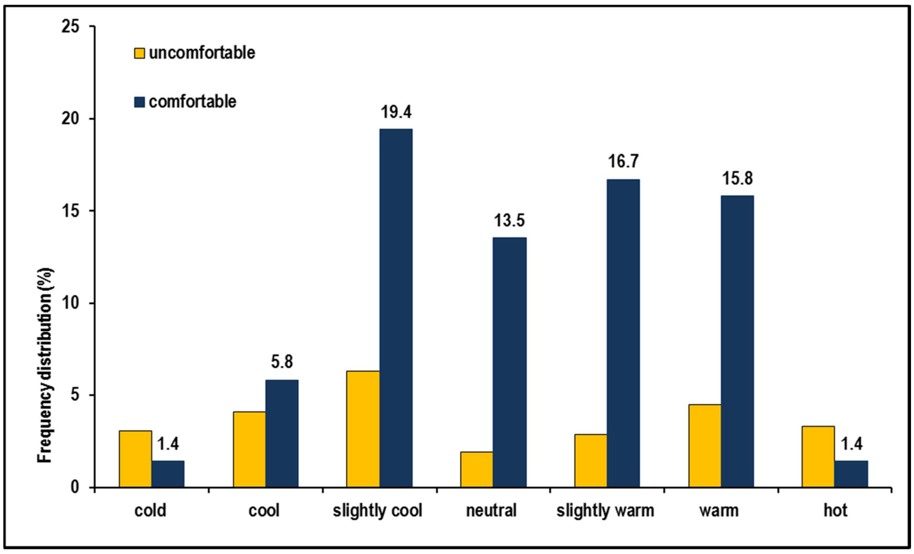


Figure 8.9. Cross-tabulation of the combined overall comfort votes versus thermal sensation categories.

By-season analysis showed that in spring (Figure 8.10) the votes centring on the three central categories accounted for almost the same percentage of total comfortable votes (74%) as the two warmer categories and neutral category (60.5%). However, in the other two seasons votes were skewed toward the warmer (summer) and cooler (autumn) end of the ASHRAE scale. In summer, from 72.1% total “comfortable” the proportion of the votes cast for the central categories (47.5%) was smaller than that in warmer categories (+1, +2) and the neutral category (0) with 56.3%. In autumn, the votes were concentrated around the two categories of cold feeling (-2, -1) and the neutral sensation (0) with 50.2. In contrast the three central categories only had 36.7% of total votes.

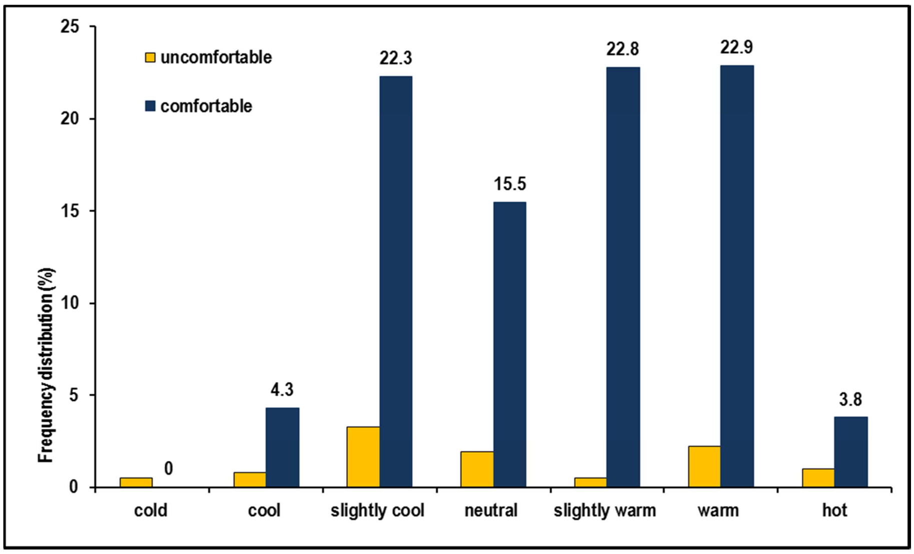


Figure 8.10. Cross-tabulation of the overall comfort votes versus thermal sensation categories in spring.

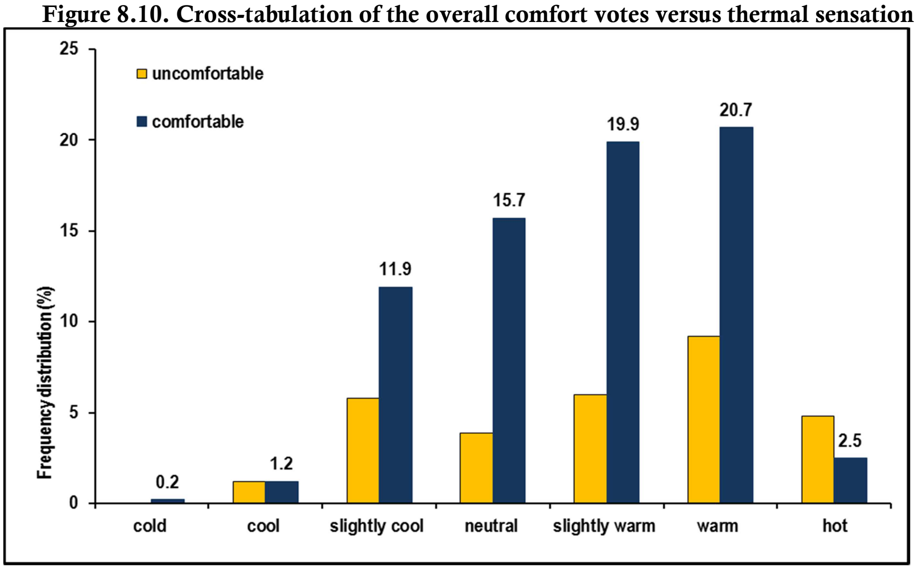


Figure 8.11. Cross-tabulation of the overall comfort votes versus thermal sensation categories in summer.

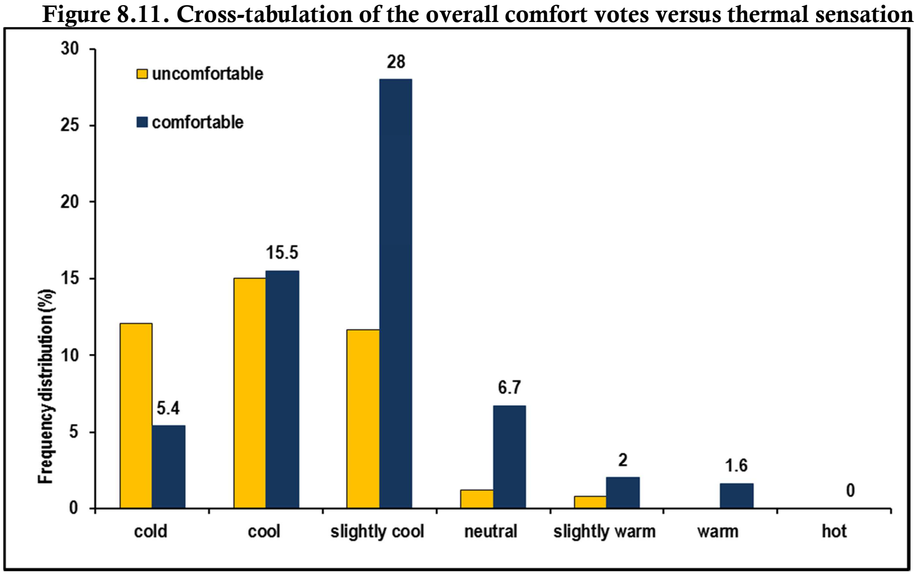


Figure 8.12. Cross-tabulation of the overall comfort votes versus thermal sensation categories in autumn.

Analysis of the thermal votes cast on the various scales regarded indicates that the ensuing neutral sensations are not necessarily the optimal or preferred thermal state for individuals. The findings also provide evidence for refuting the assumption that individuals will feel thermally dissatisfied at the extreme thermal sensations. Indeed, a noticeable proportion of thermal votes indicating thermal satisfaction in a range beyond the three central categories of ASHRAE scale showed that the extreme sensations might not always be representative of thermal discomfort. Brager et al. (as cited in Fountain et al. 1996) propounded the idea that " *thermal sensations outside of the three central categories of the ASHRAE 7-point scale do not necessarily reflect discomfort for a substantial proportion of people"*(p. 181).

A case in point is that in spring almost 20% of the participants who perceived thermal conditions "warm" or "hot" preferred "no change" in the current thermal conditions. 28% of them found these conditions acceptable and over 20% felt thermally comfortable. These proportions are small yet significant and suggest that individuals who voted for the extreme categories of thermal sensation scale may still be satisfied with their thermal environment. These findings pointed to the fact that if the basis of assessment of thermal comfort conditions is the three central categories of ASHRAE scale, it is possible the reality that participants experiencing non-neutral sensations could be overlooked. They may still regard the thermal conditions as satisfactory/acceptable. As indicated in Fountain et al (1996), neutrality is not necessarily perfect for a large number of people. This contradiction suggests that comfort relies on a connotation of neutrality that may not be appropriate.

8.4.2 NEUTRAL TEMPERATURE VERSUS PREFERRED TEMPERATURE

The cross-evaluation of neutral and preferred temperature in different seasons revealed different change patterns (6.12.1) which was greater T_{pref} than T_n in cold and transient seasons and vice versa in hot seasons. These tendencies were also found in a relatively similar context (Spagnolo and de Dear 2003, Lin et al. 2011) or other climate conditions (Huang et al. 2015, Zhao et al. 2016, Elnabawi et al. 2016). In contrast, some examples proved otherwise (Lin 2009, Salata et al. 2016, Middel et al. 2016, Yang et al. 2013a, Wang et al. 2017). Consequently, various explanations have been put forward to partially establish the discrepancies in thermal perceptions pattern found in these studies. While Spagnolo and de Dear (2003) attributed them to the psychological concept of alliesthesia in that people yearn for opposite thermal conditions as they have experienced for a certain period, Wang et al. (2017) made a general conclusion that residents of temperate regions tend to indicate their preferred conditions as warmer even when feeling warm already. Lin et al. (2011) believed that this difference is rooted in a 'semantic artifact' hypothesis, suggesting that individuals may characterise their preferred thermal state with different adjectives in different seasons. According to this hypothesis Lin et al. (2011) stated that "*one would expect preferred temperature in the hot season to be cooler than the corresponding neutral temperature … cool season preferences would be warmer than the corresponding neutral temperature*" (p. 311). The comparisons between findings in this study and that in previous studies are presented in Section 8.5.

As shown in the previous section, these differing trends highlight the fact that thermal neutrality is not always an appropriate platform for projection of thermal comfort. In effect, as opposed to the traditional notion of comfort theory equating the "neutral temperature" with thermal satisfaction, thermal neutrality does not necessarily correspond to optimal/ideal thermal state. Hence, this study rejected the assumption of a correlation between thermal acceptability and specific categories of thermal sensation on the ASHRAE TSV scale. Therefore, the thermal responses achieved in the RUCC study questioned the applicability of comfort theory, initially developed for indoor conditions, in outdoor contexts with respect to thermal neutrality.

8.4.3 ACCEPTABLE (OPTIMAL) THERMAL RANGE

Two scales of thermal perceptions (i.e. thermal sensation and direct thermal acceptance) were used to determine the optimal range. As shown in Figure 8.13, using these two scales and a threshold of 80% of thermal acceptability yielded different optimal ranges. T_n calculated by both regression (22 ˚C) and probit (21.1 ˚C) analyses fell within the optimal thermal range obtained from the three central categories of thermal sensation scale (19.8-24.1 ˚C), which is recommended by ASHRAE, and direct thermal acceptance scale (14.1 to 33.1 ˚C). However, T_{pref} determined by regression

(25.3 ˚C) and probit (24.3 ˚C) analyses were beyond the ASHRAE-55 recommended optimal range. Nonetheless it was within the range obtained from direct thermal acceptance (Figure 8.13). This finding again suggests that the recommendations on determining the optimal thermal range, enshrined in comfort standards, failed to represent the ideal or preferred thermal state for outdoor users of open spaces in the RUCC study. Hence, applying these standards in the context of this study does encounter some limitations.

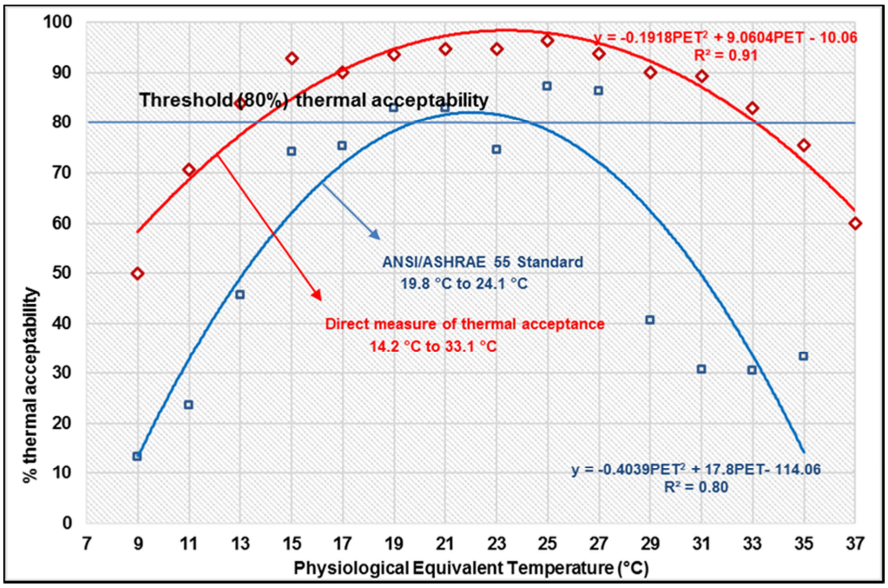


Figure 8.13. Optimal (acceptable) thermal range for the period of study by various methods.

Some researchers investigating indoor air quality have already challenged the assumptions of universal standards (McIntyre 1978, Williamson et al. 1989, Brager et al. 1993, Kwok and Chun 2003, Andamon 2005, Humphreys and Hancock 2007, Van Hoof 2008). These researchers have emphasised the necessity for revising the 'philosophy' that forms the comfort standards, which was the stance taken by the adaptive approach to thermal comfort. The challenge in the revision process is the redefinition of *"contemporary meaning and expectations of comfort"* (Shove 2003). Accordingly, it is important to understand the meaning of comfort in the right context, as this very complex concept is bound to several known and unknown contextual factors for example dominant culture, social norms, and psychological status just to name few. In effect, these factors influence thermal expectations and preferences, which might lead to changing thermal comfort requirements. The characteristics of these factors are to be fully understood for outlining effective and precise boundaries of thermal comfort conditions that are context-specific. In the same line of reasoning, Andamon (2005) explained that "…*technological advancement in the capacity to change the indoor environment, by cooling in the case of tropical Philippines, has reconfigured the meaning of comfort. Everyday life involves conformity to social norms, thus it would seem that the cooling practices, having modified convectional ways of life, have become socially patterned* (p. 233). In the indoor context, this ambiguity may be a source of confusion when adjusting the comfort temperature in buildings per the building codes and occupants' expectations. In outdoor settings, it is more critical in the development of guidelines specific to outdoor thermal comfort as these navigate the very measures taken to enhance outdoor climate conditions. These measures generally have large costs implications.

8.5 COMPARATIVE EVALUATION OF ANALYTICAL RESULTS WITH PREVIOUS STUDIES

In evaluating how the context is influential in defining people's thermal comfort requirements, the comfort characteristics obtained in this study were compared to those of previous studies. This comparison provides insights into the modifying impact of context on comfort conditions. Table 8.1 compares the specifications of outdoor thermal comfort requirements obtained in different climates, contexts and geographical zones. In terms of thermal neutrality, it seems that people living in hot and tropical regions had higher T_n compared to those in non- tropical regions. The T_n of Taiwanese (Lin and Matzarakis 2008) and Singaporeans (Wei 2014) was 27.1 ˚C and 28.1 ˚C, respectively, higher than those of the RUCC study (22 ˚C) and in a study conducted in the Mediterranean climate (22.5 ˚C). This disparity not only indicates thermal adaptation across the various climates but also reflects the role of context in the formation of thermal comfort requirements.

The comparison of the optimal thermal ranges, defined using the three central categories of the ASHRAE scale, also suggested variations in the ranges of thermal satisfaction between different contexts. The comparative evaluation proved that residents of tropical and hot climates were more tolerant to higher ranges of PET values. Comparison between preferred temperature calculated in the RUCC study and other studies demonstrated contradictory patterns in the change of this indicator of thermal perceptions with season. While almost in all studies in comparison users indicated higher and lower T_{pref} in warm and cool seasons, respectively, the results in this and another Australian-based study (Spagnolo and de Dear 2003) showed the opposite. As tabulated in Table 8.1, the comparison between results of the latter studies revealed some similarities in requirements of thermal comfort among the survey population despite exercising a different assessing protocol and study population. The comparison identified the variation in T_n and T_{pref} followed similar patterns. For instance, in the case of T_n the values were PET: 21.2 ˚C vs. 22.9 ˚C in the hot season, PET: 27.1 ˚C vs. 28.8 ˚C in the cool season and PET: 21.1 ˚C vs. 24.4˚C throughout the year. The consistency found between the patterns of change in the measure of thermal satisfaction in these two Australian cities once again proved that context dictates people's thermal expectations and preferences. In other words, the thermal conditions assumed satisfactory in one society will become a social norm and are typically shared among the members of that society.

Table 8.1. Comparison of thermal comfort conditions in different geographical conditions.

Source	Climate conditions	City	Indices used	Acceptable thermal range (˚C)	Neutral temperature (˚C)			Preferred temperature(˚C)			Population target	No participants
					Hot season	Cold seasons	Combined	Hot season	Cool seasons	Combined		
RUCC study	Oceanic temperate	Melbourne	PET OUT-SET UTCI	19.8-24.1 16.8 - 25.5 16.1 - 21.7	21.1 19 20.7	27.1 32.1 42.2	22 20.4 19.7	14.6 11.8 16.7	32.8 35.3 37.7	25.3 23.8 22.6	University campus users	1023
Salata et al. (2016)	Mediterranean climate	Rome	PET	21.1-29.2	26.9	24.9	24.9	24.8	22.5	-	University campus users	941
Elnabawi et al. (2016)	Hot and dry, Cairo		PET	23-32	29.5	24.3	-	29	24.5		Pedestrians	320
Wang et al. (2017)	Mild maritime	Groningen	TOP		22.2	-	-	35.7	-	-	University campus	389
Wei (2014)	Tropical monsoon	Singapore	PET OUT-ET* UTCI	<32.5	-	-	28.10	-	-	-	University campus users and publics	2036
Watanabe et al. (2014)	Humid subtropical	Nagoya	UTCI OUT-SET*	-	34 28.9	-	-	-			Colleague students	42
Yahia and Johansson (2013)	Hot and dry	Damascus	PET OUT-SET*	18-28.7 25.6-44.6	15.8 23.1	23.4 35.1	-	-	-	-	Park and residential areas users	920
Ng and Cheng (2012)	Sub-tropical	Hong Kong	PET	-	27.9	16.3	-	-	-	-	Passers-by	2702
Mahmoud (2011)	Dry sub-tropical	Cairo	PET	22-30 (hot) 21-29 (cold)	30.1	29	-	-	-	-	Urban park users	300
Lin (2009)	Humid sub-tropical	Taichung city	PET	21.3-28.5	25.6	23.7	-	24.5	23.0	-	Urban square users	1099 0
Lin and Matzarakis (2008)	Tropical	Taiwan	PET SET	21.6 – 35.4	-	-	27.17	 28.5	 26.7	-	Tourists	1644
Spagnolo and de Dear (2003)	Semi-tropical	Sydney	PET OUT-SET	- -	22.9 23.3	28.8 33.3	24.4 26.2	23.4 24.1	30.9 38	25 26.8	Public places visitors	1018

8.6 EFFECT OF SEASON ON THERMAL RESPONSES AND USAGE PATTERN

Characterisation of thermal comfort requirements throughout a year cannot provide a clear picture of the extent of people's thermal satisfaction in climates with distinct seasons. The results of this study proved that people had varying thermal expectations and preferences in different seasons, thus highlighting the role of seasonal change in determination of thermal comfort in outdoor spaces. As opposed to indoor conditions with limited variations in thermal conditions, seasonal change has a large impact on people's thermal perceptions. As proved in Chapter 7, seasonal change not only modifies thermal expectations and preferences through imposing different climate conditions but also controls the moderating impact of contextual factors on the relationship between people's thermal sensation and local microclimate. The former possibly modifies the human body's thermoregulatory system in different ways since the body's physiological reaction varies across seasons. The latter becomes effective given the fact that sometimes a contextual factor thermally pleasing people in one season could be a source of thermal discomfort in another. Largely, the information derived from field surveys in each season provides an opportunity for developers to make informed decisions regarding season specific comfort requirements. They can effectively plan and build spaces with thermally comfortable conditions in different seasons.

Furthermore, the results on the relationship between usage pattern and local microclimate in different seasons also pointed to the impact of seasonal change on people's attendance in outdoor spaces (Section 6.16.1). This finding also has implications for exercising the best practice management of outdoor spaces as the usage of this spaces in an education precinct contributes to enhancing life quality and academic performance. In other words, if urban planners and space managers understand the seasonal comfort requirements in outdoor spaces they will be more likely to effectively plan for providing the conditions that encourage more people to use outdoors, with more frequent and longer visits.

8.7 RECONFIGURATION OF THERMAL PERCEPTION AND COMFORT PREFERENCE

As indicated before, to accurately interpret the comfort field survey data obtained from assessment of thermal comfort in one context, one should delve into the characteristics of that context. This also: firstly, provides an explanation regarding why the assumptions enshrined in thermal comfort standards are not directly applicable in the given context; and secondly, shows how the meaning of thermal comfort is reconfigured among people residing in a context. Accordingly, it helps researchers in the field of outdoor thermal comfort revise the assumptions related to the definition of thermal satisfaction in accordance to current real world conditions.

For this reason, the study has developed a multi-model framework to delineate the quality of reconfiguration of thermal perceptions and comfort preferences among RUCC open space users. Particularly, the focus is on explaining the existence of a mismatch between interpretations emerging from using different perceptual comfort indicators about thermal satisfaction. Specifically, the differences between people's thermal sensations and thermal preferences are established here. As depicted in Figure 8.14, this framework consists of three theories/models together clarifying the fundamental reasons producing such differences that are also affecting thermal satisfaction in open spaces. Included in this framework are: "alliesthesia" which is concerned with the desire for change in thermal conditions; "SESM" investigating the impact of contextual factors on thermal sensation in line with adaptive theory; and "rising expectations" which explains thermal expectations of the survey population.

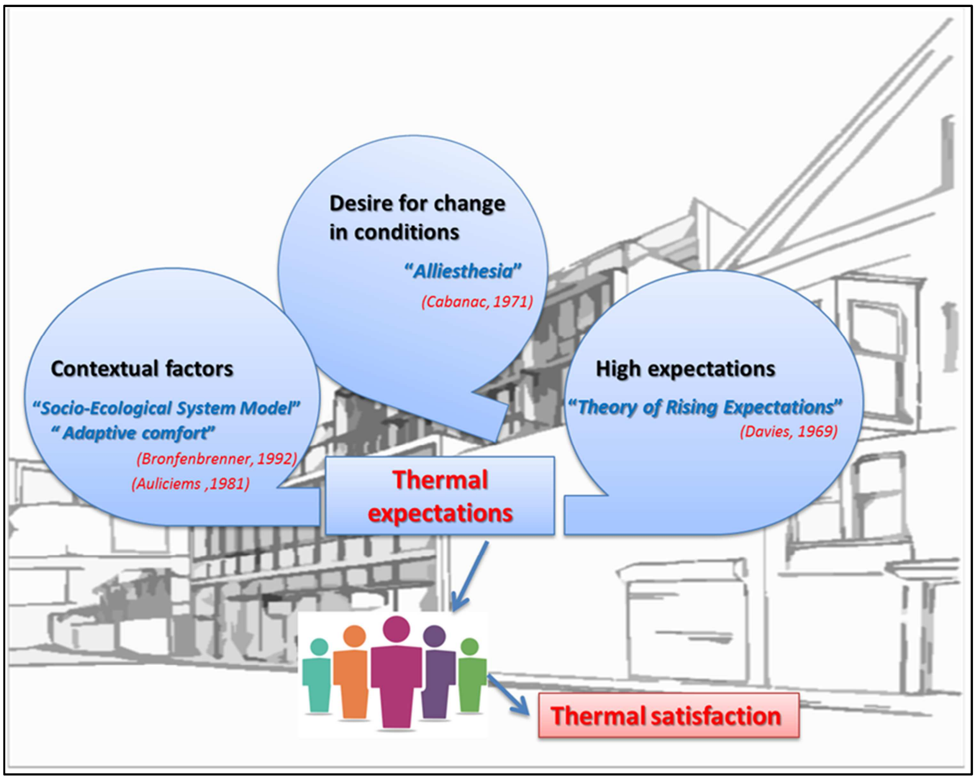


Figure 8.14. Reconfiguration of thermal expectations and satisfaction within RUCC open spaces.

8.7.1 THERMAL PLEASURE AND THERMAL PERCEPTIONS

As indicated earlier in Chapter 4 (Section 4.2.2) applying the psychological concept of alliesthesia in thermal comfort relates to short and long-term thermal experience and expectations of thermal conditions (Spagnolo and de Dear 2003, Krüger et al. 2015). The findings of this study have partially proved the role of alliesthesia in shaping people's thermal expectations and thus thermal preferences in different seasons. The fact that survey participants rated higher T_{pref} in spring, autumn, and excessively less so in summer is an indication of the impact of alliesthesia.

In spring, experiencing a long period of cold thermal conditions during six cold months of autumn and winter in Melbourne, people were still subject to unstable weather conditions during this transient season, making them prefer warmer thermal conditions (positive alliesthesia). This assumption is supported by the results derived from attributing the measured thermal conditions to comfort predictions and the respective physiological thermal stress in this season (Figure 6.23). According to these predictions, in spring people were subject to cold stress extending from 11.1% in Site 1 to 47.6% in Site 2. Besides, according to thermal preferences votes (Table 6.12) the participants in this season preferred warmer conditions (30%) twice as much as cooler conditions (15%) resulting in people's T_{pref} of 26.4 ˚C by regression (Table 6.18) and 27.5 ˚C by probit analysis (Table 6.20).

In February 2015, the last month of that year's summer in Australia, the situation was quite opposite to that in November. By this season, people had experienced prolonged hot conditions. According to predictions (Figure 6.23), during this month, people on average were more subject to heat stress (46.5%), than neutral conditions (12.9%) and cold stress (20.5%). Indeed, the impact of the environmental stimuli (higher temperature) which is a psychological mechanism of thermal adaptation producing pleasure in spring was no longer effective, and was gradually being diminished. It led to unpleasant thermal conditions (negative alliesthesia). Hence, participants began to seek cooler conditions (positive alliesthesia). In this month, the percentage of people wanting cooler conditions was almost more than three times larger than those longing for warmer conditions (Table 6.12) and T_{pref} computed as 14.6 ˚C by regression (Table 6.18) and 15 ˚C by probit (Table 6.20) which are much lower than those in Spring. In this regard, Fountain et al. (1996) argued that change in thermal expectations occurs "*…when a person's individual 'comfort setpoints' (or preferred temperature) track the* *cycles and variations in indoor climates, which in turn may follow the diurnal or seasonal outdoor climate patterns, or indeed, longer-term climatic changes."* (p. 181).

In the last month of autumn (May 2015) there was a significant drop in temperature as it reached 9.5 ˚C (Table 6.3) and consequently people severely became subject to cold stress (Figure 6.23); with 39.3% having "slight cold stress", 42.8% "moderate cold stress" and 10% "strong cold stress". For the same reason and in line with positive alliesthesia, many people in autumn (67%) required warmer thermal conditions in autumn (Table 6.12). In autumn, the T_{pref} were 32.8 ˚C by regression (Table 6.18) and 32.1 ˚C by probit (Table 6.20). The fairly similar values were found in studies conducted in Sydney (Spagnolo and de Dear 2003), Damascus (Yahia and Johansson 2013), and Groningen (Wang et al. 2017). Contrary conditions were also observed in other examples including Cairo (Mahmoud 2011, Elnabawi et al. 2016), Rome (Salata et al. 2016), and Hong Kong (Ng and Cheng 2012).

Alliesthesia also affects people's thermal sensation in a different way. This impact is built on the proved relationship between thermal sensation and users' short-term thermal experience and the length of exposure to environmental parameters. As indicated in the literature review, people in developed countries spend most of their time indoors (Leech et al. 2002). The results of SESM analysis in the physical environment (Table 7.5) showed that the "time of exposure" is a critical factor in the creation of thermal sensation. As most participants were transient users visiting the study sites for a short time, particularly sites 1 and 2 (Figure 6.27), their time of exposure to outdoor weather conditions and previous thermal history played a significant role in shaping their thermal expectations. These transient users had stepped into the study sites from an air-conditioned classroom/office (Table 6.26) and confronted a thermal scenario very different from what they experienced before, particularly in severe microclimate conditions. As result, they had limited opportunity to be exposed to an outdoor thermal environment enough to thermally adapt to the weather conditions. Therefore, due to short visits alliesthesia in the mould of thermal pleasure had some impacts on their thermal perception that would have diminished if they had adapted to outdoor conditions.

8.7.2 THERMAL EXPECTATIONS AND THERMAL PERCEPTIONS

It has long been known that thermal expectation is a major contributor to the creation of thermal perceptions and thermal comfort (Auliciems 1981). McIntyre (1981) recognised the significance of expectations in thermal comfort as "…*a person's reaction to a temperature which is less than perfect will depend very much on his expectations, personality, and what else he is doing at the time"*(p. 201). According to the expectation hypothesis (Fountain et al. 1996), an expectation influences individuals' attitude towards the achievement of thermal comfort (Halawa and van Hoof 2012). Therefore, it is important to understand the determinants of thermal expectations in the context where people seek thermal comfort. As indicated in Chapter 4 (Section 4.2.3), the theory of rising expectations (Davies 1969) seems to be an appropriate platform for understanding these determinants in this study's context.

Australia as a developed country with a strong economy has managed to retain high living standards for most of its residents; hence, Australians generally set high expectations compared to people in less developed countries. In 2015, Australia was ranked above countries such as the UK, Germany, and France in terms of purchasing power parity; the Australian per-capita gross domestic product (GDP) was recorded as 44,570 USD (The World Bank 2015). The country secured the second and sixth positions in the United Nations "Human Development Index" in 2011 and the "Economist Worldwide Quality-of-life Index" in 2005, respectively (Weinberg and Cummins 2015). Melbourne in particular has been the world's most liveable city for six consecutive years since 2010 (Economist Intelligence Unit 2016). All these statistics point to the improvement in the quality of life in Australia (Weinberg and Cummins 2015).

As the target population in this study also is comprised of international students it is critical to investigate their expectations of outdoor thermal conditions. International students enrolled in Australian educational institutions are usually from financially privileged families who can afford high-priced tuition fees and living expenses. Education in Australia requires reasonable financial resources to cover these expenses. According to the Hong Kong and Shanghai Banking Corporation (HSBC) global report (HSBC 2014), titled *The Value of Education: Springboard for success*, Australia is the most expensive place for education for international students. The financial contribution these students make to the Australian economy is considerable. In the 2014–15 financial year, the ABS (cited in Deloitte Access Economics 2016) valued exports from international education at $18.8 billion, which is the third national greatest export. Overall, their financial situation generally makes them set higher expectations for living standards.

The employees working in the CBD neighbourhoods including RUCC tended to visit RUCC open spaces seeking an environment to take a break or have their lunch. These professionals usually have good financial conditions knowing that improvements have occurred in the economic profile of Melbourne's central region (City of Melbourne 2016). According to anecdotal evidence, these employees work in air conditioned offices encouraging them to maintain higher ergonomic conditions including indoor thermal conditions. Therefore, they have altered thermal expectations in the face of outdoor weather conditions where their thermal expectations altered.

Taken together, the research findings showed that the users of RUCC open spaces had unrealistically higher expectations of thermal conditions outdoors. Although the participants indicated a high rate of thermal acceptability by voting on direct thermal acceptance scale they still hoped for changes in thermal conditions to achieve better thermal comfort in different seasons. This assumption is supported by preference responses on desire to change in T_a (52%), T_g (46%), V_a (46%), and RH (23%). This is particularly interesting as these changes were requested while some research has shown that many Australians are aware of climate change consequences and expect undesired climate events to occur throughout the year. In one study, for instance, more than two thirds of Australian participants expressed their expectations of change in climate and more extreme climate events (Leviston et al. 2015). However, it seems that in our study such knowledge was not effectively shared with the users of RUCC open spaces as it did not alter participants' expectations of the outdoor thermal environment they encounter every day. Alternatively, the precinct authorities failed to share their knowledge of local climate with the international students.

8.7.3 CONTEXTUAL FACTORS AND THERMAL PERCEPTIONS

The role of contextual factors on people's thermal expectations and thus thermal sensation in the form of adaptive models has become an integral part of thermal comfort research. However, the current adaptive models failed to provide an effective process to consider their impact on people's thermal judgements particularly in outdoor spaces. From the thermal comfort perspective, investigating the role of contextual factors when creating people's outdoor thermal sensation, provides detailed information to explain the observed divergence between their T_{pref} and T_n. Therefore, this study used the socio-ecological system model (SESM) to investigate the extent of the effect of contextual factors on people's outdoor thermal sensations. As stated in Chapter 4 (Section 4.2.1), SESM contains five environments whereby the effects of clusters of factors on thermal sensations were investigated. Included in the five environments of SESM are "individual", "social", "physical", "psychological", and "policies and standards" (Figure 4.1). The collective and individual effects of these environments on thermal sensation and other elements of thermal perceptions were analysed and reported in Chapter 7 and are accordingly discussed in this chapter. The results proved that some of these factors partially influenced people's sensations (Table 7.10).

Presented below are the discussions on explaining how these non-thermal factors influenced thermal expectations and thermal sensations. However, for the last SESM environment (policies and standards) only the relationship between the policies and thermal perceptions was explored. The corresponding discussions in the following sections contribute to addressing the second research question investigating the extent of contextual impact on people's thermal sensations. Furthermore, these discussions draw the attentions of thermal comfort scholars to actively consider contextual factors when assessing thermal comfort. Some attempts have been made to consider a few of these factors in thermal comfort assessment using various models such as the Rayman Pro model (Matzarakis et al. 2007), Fiala model (Bröde et al. 2012a) and Comfort Model STDOUT (de Dear 2013). Integrating these factors in regression models, very few research analyses have also proposed adaptive models for the assessment of outdoor thermal comfort in various climates including semitropical (Thitisawat et al. 2011) and arid regions (Ruiz and Correa 2014). The prediction results, however, have shown that these models do not reflect the impact of context as there was no tangible change in predictions with and without them and above that, their validity is yet to be confirmed. Overall, there is an urgent need to develop models that can accurately predict outdoor thermal comfort requirements by explaining the influence of contextual factors. These models can be based on the field survey data obtained in different regions, which potentially have precise predictions tailored to each context. In this study in total 29 contextual factors, under four SESM environments were investigated. Of that number, only 12 factors were found to meaningly influence outdoor thermal sensation throughout the study period, which together could explain 7.1% of variation in people's thermal sensations.

8.7.3.1 INDIVIDUAL ENVIRONMENT

The participants' gender, age group, level of activity, clothing insulation, exposure to sun, and skin colour were the factors investigated under the individual environment. Overall, the results showed that not all the factors under this environment played a mediating role in the perceptions of outdoor thermal conditions (Table 7.1). Gender was found to be insignificant in moderating the effect of thermal conditions on users' thermal judgement. The results showed that the genders not only perceived thermal conditions roughly the same, but also maintained a very similar pattern throughout the study period. The results have confirmed the findings of other studies wherein the gender was not influential factor on thermal perceptions (Knez and Thorsson 2006, Krüger and Rossi 2011, Pantavou et al. 2013). One possible explanation for such findings could relate to the higher proportion of uniformity among the outdoor users who were mostly young students. Such uniformity among the occupants of a space further emphasised the importance of defining thermal comfort requirements within the context. There is also a social overlay of gender equality which helps interpret this finding; in Western culture, “gender quality” has changed the social norms and behaviours of people. This change has led to a homogenised society in which genders’ attitudes and reaction to various phenomena including interaction with outdoor spaces do not substantially differ. Hence, female and male participants did not have varying thermal perceptions of study spaces. Conversely, in Asian cultures the gender equality is not developed so, for instance, Tung et al. (2014) found that female pedestrians in Taiwan had less thermal tolerance, this phenomenon was then liked to the social norms and behaviour learning process through which Taiwanese’ women are encouraged to avoid harsh climate conditions in the interest of having a light skin colour.

Age group was found to influence the thermal sensation, and according to previous studies it can alter thermal sensations in different ways. The impact is primarily linked to the physiological conditions in different stages of people’s lives as it governs the activity and metabolic rates, which are influential factors in attainment of thermal comfort., Kalkstein (1997) argued that elderly people are in general more sensitive to heat and Penwarden (1973) asserted that windy conditions may be a serious environmental hazard to elderly or infirm people than to fit and active ones. Additionally, age is a decisive factor in choosing the form of clothing worn and the level and type of activity performed (Oliveira and Andrade 2007, Parsons 2003). These characteristics also affect the basal metabolic rate of heat production, which normally declines with age (Parsons 2003). The physiological conditions also determine the way individuals interact with surrounding physical conditions, which indirectly influences thermal perceptions. Lastly, a range of psychological differences, depending chiefly on age of an individual, can be attributed to the way that individuals perceive environmental conditions (Oliveira and Andrade 2007, Lai et al. 2014a). The study could not find an individual effect of skin colour on the variation of thermal sensation; however, in interaction with other factors its effect was found to be meaningful.

The level of clothing insulation was found to be statistically related to TSV; this finding corroborates the foundations of heat balance theories in which this factor accounts for physical thermoregulation (Gagge et al. 1986, Fanger 1970) as well as the results of previous studies (Parsons 2002, Lin et al. 2013a). The level of clothing insulation is an adaptive opportunity (adjustment behaviour) people may consider when coping with various climate conditions. Several researchers (Nikolopoulou et al. 2001, Walton et al. 2007, Oliveira and Andrade 2007, Mahmoud 2011) observed that outdoor users tend to enhance thermal comfort by altering their clothing. As shown in Figure 7.2, the non-linear relationship of clothing insulation and thermal condition is indicative of thermal adaptation over the study period. Interestingly, the fact that people tended to increase their clothing with increase in a temperature after a certain thermal point represents how people actively reacted to the current thermal conditions. People started to increase their clothing with PET value to protect the skin surface from excessive solar exposure and the dangers of radiative temperature and solar UV on the human body. This non-linear relationship has been reported in a study carried out in Lisbon (Oliveira and Andrade 2007). Despite its known effect on people's thermal comfort the results showed that the level of activity was not statistically related to the variation of users' TSV. One possible explanation can be the poor estimation of participants in specifying their last activity prior to surveys.

The posture of participants in this study was not an explanatory factor for the resulting TSV variations. As the study site was often visited for only a short time it is possible that the actual effect of body posture on thermal sensation was not captured during the surveys. In addition, most participants were approached when they were passing by and completed the questionnaire in the standing or sitting position in a short time. This finding confirms the outcome of a research conducted in a cold environment (Donaldson et al. 1996) and disagrees with other studies in temperature controlled rooms (Tikuisis and Ducharme 1996, Parsons 2003, Kurazumi et al. 2008).

8.7.3.2 SOCIAL ENVIRONMENT

The second environment of the SESM model, social environment, includes the parameters for social context. The analytical results of the three factors of users' companionship, position, and climatic background showed these factors did influence people's thermal sensation (Table 7.4). It was already identified that visiting a space with company has a mediating impact on thermal perceptions (Oliveira and Andrade 2007, Pantavou et al. 2013). The meaningful difference between the users who were accompanied and those who were not implies the role of social context in the interaction between people and the thermal environment. Furthermore, it appears that being in others' company will make people less sensitive to outdoor thermal conditions (Table 7.3).

The results proving the influence of position/occupation on thermal perceptions were consistent with previous analyses (Aljawabra and Nikolopoulou 2010, Indraganti and Rao 2010), although it is noted that the variety of occupations in this study was limited by the population studied being quite homogenous. Future studies targeting a non-uniform population may provide more insights into the factors moderating the effects on thermal perceptions. The impact of climate (cultural) background was significant in the thermal perceptions of people in this study. In line with the findings of some recent thermal comfort studies in outdoor conditions (Knez and Thorsson 2008, Kenawy and Elkadi 2013), and some far earlier in indoor conditions (Nicol 1974), climatic background was found to moderate people's thermal judgement. It is assumed that the influence of this factor is connected to both "long- term thermal history" (acclimatization to particular climate conditions) and the "social context" that may mediate thermal adaptation via cultural adjustment (Brager and de Dear 1998). The time required to adapt to new thermal conditions can range from a few minutes to put on a coat, a few hours to realise what is right to put on in current given thermal environments, to indefinitely long if the adaptation causes an individual to transgress a noticeable cultural convention (Humphreys and Nicol 1998).

8.7.3.3 PHYSICAL ENVIRONMENT

Discussed in this environment are the results following on from the analysis of environmental parameters, physiological adaptation (i.e. length of residence, time of exposure to the given environment), thermal history, and type of user. The findings on the design descriptor are separately discussed in Section 8.10. The analytical findings on the relationship between the meteorological conditions and thermal sensation suggested that up to 56.1% of variation in TSV is explained by the collective effect of the four environmental variables and two personal factors (PET predictions). While the results agree with those reported in previous studies (Nikolopoulou et al. 2001, Vanos et al. 2012, Yahia and Johansson 2013, Pearlmutter et al. 2014), it is representative of the influence of other non-thermal factors in the prediction of thermal comfort conditions. Simply put, thermal conditions could not describe the conditions of the thermal perceptions outdoors.

According to the concept of thermal adaptation and acclimatization in particular, people are expected to be gradually acclimatized to local microclimate when they are repeatedly exposed to it (Humphreys 1975, de Dear and Brager 1998). This process is otherwise known as physiological thermal adaptation (de Dear and Brager 1998) Also, extended exposure to outdoor environmental stimulus induces the reflective physiological thermal adaptation but in less time (Humphreys and Nicol 1998, Krüger et al. 2015). Time of exposure was also categorized under psychological thermal adaptation by Nikolopoulou and Steemers (2003). Krüger et al. (2015) indicated that "...*stepping from thermal homogeneity to transient outdoor conditions should create immediate responses that would then diminish with time of exposure*" (p. 1).

In the RUCC study, it was found that while short-term adaptation to the weather conditions occurred with a statistical influence on thermal sensation, the length of stay in Melbourne did not emerge as a significant determinant of thermal sensation. Nikolopoulou and Steemers (2003) stated that "…*exposure to discomfort is not viewed negatively if the individual anticipates that it is short-lived, such as getting out of a warm car to enter a building in winter, and no significant dissatisfaction is caused*..." (p. 97). Furthermore, the time of exposure to outdoor thermal conditions was also assessed by indicating whether the survey participant was a transient user of the space or otherwise. Findings for autumn (data only available for this season) failed to prove the statistically significant difference between such categories.

8.7.3.4 PSYCHOLOGICAL ENVIRONMENT

Psychological aspect of comfort is considered a vital element in the formation of thermal perceptions (Nikolopoulou and Steemers 2003). The effect of psychological parameters on thermal judgement is typically known to be imposed through thermal adaptation and modifications in thermal expectations. As indicated in Chapter 3, several studies have shown evidence of thermal adaptation. Some of these also identified the mechanisms of such adaptation that were physiological (de Dear et al. 1997), psychological (Nikolopoulou and Steemers 2003, Knez et al. 2009) and behavioural (Cheng et al. 2009, Wu et al. 2015). Using the aggregated data, this study tested 10 parameters on thermal adaptation (frequency and purpose of visit, seasonal change, perceived control, overall comfort, thermal preference, weather forecasts, place characters, naturalness, and spatial features). However, only seasonal change, thermal preference, overall comfort, and one sub-factor - “an environment with better ambient conditions” - were found to statistically impact on thermal sensation (Table 7.7). Accounting for these factors in the final regression model for this environment, the prediction ability of the model improved by only 5.6%, indicating a low level of influence.

The evident relationship between overall comfort and thermal sensation was already reported in studies assessing outdoor thermal comfort (Cheng et al. 2012, Pantavou et al. 2013, Zhang and Zhao 2008). Overall comfort may not be only related to weather conditions but to psychological factors by moderating thermal expectations. Indeed, overall comfort within a thermal condition as a function of thermal perceptions differs from thermal sensation. Thermal comfort is the expression of satisfaction with the environment while thermal sensation is the expression of someone’s evaluation of thermal conditions. With these definitions, one notes there are psychological differences between these two concepts. Thermal comfort then is not an evaluation of what is sensed outdoors but an expression of the satisfaction with the given circumstances irrespective of thermal conditions. Such a conclusion was confirmed when the results demonstrated a negligible correlation between PET values and overall comfort (Table 6.16). However, as suggested by the results the level of satisfaction with the surrounding environment expressed through the categories of overall comfort scale can partially influence outdoor evaluation of thermal conditions. When the outdoor spaces to be built comply with the users’ overall comfort and satisfaction, this will have a positive impact on users’ outdoor thermal sensation.

Thermal preference was also found to be in a significant relationship with variation of thermal sensations. As this scale measures how people define their desire for current thermal conditions such a significant relationship between represents an association between thermal perceptions and thermal expectations. This link was first identified by Auliciems (1981) and introduced through a psycho-physiological model of thermal perception; this research, however, proved that these two scales are not precisely indicating the same thermal perception due to the conceptual differences (Section 8.4.1).

"An environment with a better ambient condition" was found to modify the relationship between TSV and thermal conditions (Table 7.7). This finding refers to the fact that users who stepped out from surrounding buildings to experience a different environment tended to consider outdoor conditions a better environment; this tendency in turn modified their expectations and therefore a different thermal sensation was indicated by them particularly in summer. Seasonal change is a critical factor in determination of human thermal perceptions. Besides impacting on thermal sensation due to change in thermal conditions, seasonal change may psychologically affect people's thermal judgement in three ways: (1) by modifying people's thermal expectations from seasonal weather conditions; (2) by changes in people's thermal preference through the psychological concept of alliesthesia in which people yearn for opposite thermal; (3) and by altering the influence pattern of other determinants of TSV. The effect of the latter on study participants' TSV proved to be applicapable to the RUCC study's comfort data (Section 7.7).

8.7.3.5 POLICY AND STANDARDS

Available sources showed that current policies mostly focused on indoor settings and only contained some generic information for outdoor thermal environments. The weather forecasts are the main sources of information for outdoor users and there is possibility they prove to be wrong, therefore, the innovative ways should be considered to help people take advantage of these forecasts. Recently, with the widespread use of social media such as Facebook, Twitter and Instagram, some institutions have managed to take advantage of these platforms to develop an alarm system to warn students and staff about the occurrence of daily stressing thermal conditions.

Furthermore, as discussed in results (Section 7.6) the inadequacy of available standards on outdoor thermal conditions has emphasised the necessity of developing specific policies with the ability to effectively manage human-place relationship outdoors. From the thermal comfort perspective, the potential policies should not only aim to determine and advise the optimal thermal conditions and corresponding strategies to provide such conditions, but also deliver information on how to put into practice such policies for the better management of human-place relationships. These policies may include a description of thermal comfort conditions in relation to human health and well-being, the influential factors thereof, solutions to maximise the effect of policies in favour of better outdoor thermal experience and strategies on mitigation and adaptation to local and sometimes undesirable thermal conditions. Reviewing a number of behavioural change theories, Prager (2012) listed a number of suggestions in the literature to develop better policies that can influence people's behaviour and attitudes. He stated that the policy-maker should "…*know the target audience – different types of people react to different kind of incentives. Know what behaviour you want to change towards which other kind of behaviour; or know what kind of actions you want people to get involved in. Consider which factors are likely to influence behaviours and shortlist, which key influencing factors the policy / intervention, will target. Identify what has worked in the past. Find innovative ways of governance: rather than informing people and telling them what to do, take them on board, include them as partners in deciding on which conditions that drive behaviours should be changed and how best to achieve this*" (p. 17).

Following the change in thermal expectations people will have different thermal judgements of local microclimates they are dealing with daily. In effect, lower thermal expectations encourage people to make changes in their thermal adaptive behaviours, environmental attitude, psychological status and ultimately usage pattern. In the light of these changes, the influence of urban policies and standards on outdoor users' thermal perceptions becomes more evident. It also reinforces the connection between what is expected to be experienced outdoors and what realistically could be provided for outdoor users. A similar situation is found in indoor conditions when the notion of green building (naturally ventilated) was introduced vis-à-vis conditioned indoor spaces (de Dear and Brager 2002). The cornerstone of this notion is that people's thermal expectations will possibly change when they know the reality of thermal conditions that are not much dependent on energy intensive systems. On this matter, Nicol and Humphreys (2002) introduced the idea of "forgiveness" in natural ventilated buildings wherein people have lower thermal expectations; the authors indicated that forgiveness affects the attitude of inhabitants to buildings so that they will accept inadequacies in their thermal environment more readily.

Ultimately, these policies should be formulated in such a way to inform urban planning by incorporating various aspects of people's thermal experiences and expectations into urban plans for outdoor spaces. The availability of these comprehensive policies will minimise the ambiguities and misunderstandings emerged during the phases of developing thermally comfortable spaces including planning, designing, construction and post-occupancy evaluation and management.

8.8 COMPARISON OF PREDICTION PERFORMANCE BETWEEN INDICES

Despite observing a similar prediction trend between indices, further comparison on the thermal performance indicated that PET values had the closest coefficient slope of linear regression to that of actual thermal sensation, followed by UTCI and OUT-SET* (Figure 6.16). This finding was also confirmed by the results of ordinal logistic regression where the largest association between the actual and predicted thermal sensation was found for PET values followed by UTCI and OUT-SET* (Table 6.15). The analyses also showed that predictions' validity varied among the study seasons; when except for UTCI some better predictions were obtained in cold season (autumn) relative to hot seasons (spring and summer). These results, however, meant this pattern was inconsistent with the findings of previous studies (Spagnolo and de Dear 2003, Mahmoud 2011, Yahia and Johansson 2013). Spagnolo and de Dear (2003) linked this inconsistency to the skewed nature of thermal sensation votes in cold seasons, while Yahia and Johansson (2013) believed that slight difference in seasonal thermal conditions in warm climates caused predictions to bear no meaningful difference on thermal comfort in various seasons. Overall, it can be stated that while the steady-state indices are insufficient to predict individuals' thermal perceptions due to the reasons specified before, these indices can satisfactorily apply to our study. They can predict the averaged thermal comfort requirements for many people. Furthermore, as the comfort indices recommended in the standards are different from those devised for this study it was not feasible to compare its findings with comfort thresholds entrenched in the indoor comfort standards.

8.9 COMPARISON OF THERMAL PERCEPTIONS BETWEEN THE STUDY OPEN SPACES

Comparison of thermal responses obtained in different sites yielded some information about human-place relationships in these sites. The results indicated small but notable differences in users' thermal satisfaction at the three study sites with users of Site 2 experiencing slightly more satisfactory thermal conditions (Section 6.14) despite having the most heat-related stress conditions (Figure 6.23). This contradictory finding can be interpreted in the light of "place character" (i.e. function of place, type of user) and "spatial feature" (the level of shade), and their influence on people's thermal judgment.

Overall, the better satisfaction with thermal environment observed in Site 2 could be partially attributed to visitor's usage patterns, which often included "short visits" (Figure 6.27) with the aim of "passage to another place" (Figure 6.26). The short visits to Site 2 exposed users to outdoor meteorological conditions for a limited time. According to alliesthesia (de Dear 2011) and time of exposure (Nikolopoulou and Steemers 2003) the limitation in exposure to meteorological conditions does not induce thermal discomfort that is reflected in better people's thermal preference and acceptance (Figure 6.25). On this matter, using the concept of alliesthesia, Krüger et al. (2015) postulated that *"…stepping from thermal homogeneity to transient outdoor conditions should create immediate responses that would then diminish with time of exposure"* (p. 1). On top of that, Nikolopoulou and Steemers (2003) stated that "*exposure* *to discomfort is not viewed negatively if the individual anticipates that it is short-lived, such as getting out of a warm car to enter a building in winter, and no significant dissatisfaction is caused*" (p. 97).

The frequency distribution of thermal votes in different thermal ranges (Figure 6.25) provided a precise overview of thermal satisfaction between study sites. On average, the results showed that visitors in Site 2 were more thermally satisfied in the three thermal ranges. In the thermal range of "cooler than neutral conditions" (13-19 ˚C), this can be interpreted short visits did not influence people's thermal perceptions. Furthermore, their heavier clothing pattern and higher rate of metabolic activities were due to more movement (Table 6.6), off-setting the thermal differences between indoors and outdoors. As the main purpose of visiting was to get to another place, their thermal expectations had not been set in the way that caused them thermal discomfort.

However, in the next two thermal ranges (19-25˚C and 25-31˚C) the difference in percentage of the people's thermal preference became slighter. This trend is justified with the design of place and purpose of visit. In warm weather conditions, besides the role of purpose of visit in thermal judgement, as indicated above, the spatial design played a decisive role. In sites 2 and 3, due to the compact high-rise design and the lower SVF values the users had this chance to take advantage of shaded spots during hot thermal conditions. In Site 1 different design options including shade device, trees, water features and a café in which people purchased cold beverage contributed to higher percentage of thermal satisfaction. Largely, results demonstrated that attaining thermal comfort in outdoor spaces depended on several factors including time of the year (season), function of place, thermal expectations, type of users, spatial design characteristics. Each of these factors help create thermal comfort and cannot be separately responsible for thermal satisfaction.

8.10 OUTDOOR SPATIAL FEATURES (DESIGN) AND THERMAL PERCEPTIONS

In this study, the role of spatial features including sky view factor and surface materials in modification of thermal conditions and thermal comfort is discussed. The analytical results of the first feature proved an influence on thermal sensations (Tables 7.5 and 7.9). The results agree well with findings in previous studies (Johansson and Emmanuel 2006, Emmanuel et al. 2007, Djenane et al. 2008, Lin et al. 2010, Hwang et al. 2011, Mahmoud 2011). Further analyses also showed that SVF had a moderate to strong influence on T_a in spring and summer; varying correlation with the other environmental variables was also found over the study seasons (Table 6.5). Such correlations imply the opportunities for temporary modification in outdoor thermal conditions using natural and artificial structures implemented to create thermally comfortable spaces in each season. For instance, in hot weather conditions the shade provides structures such as trees and buildings (Wong et al. 2007, Lin et al. 2010), pergolas and shading devices (Watanabe et al. 2014). Asymmetrically, galleries, and overhanging facades (Ali-Toudert and Mayer 2007) act as a mitigating strategy to create thermal comfort by decreasing solar access and thus a drop in T_a and T_s. Walton et al. (2007) stated that "…*combining modern architecture and urban planning it is possible to adapt the wind, sun, and thermal conditions of the inner city spaces between buildings to enhance or limit wind flow and provide sunlight and shade*…" (p. 3166).

However, as indicated previously, these design options are employed for a certain period (season) and purpose. As the results suggested, a comfort providing structure in one season could be the source of thermal discomfort in another season. In the case of SVF, while the heavily shaded areas provide the best thermal comfort for hot seasons, they will cause discomfort for users during cool seasons (Lin et al. 2010). Particularly, as suggested by Lin et al. (2010) the thermal requirements of outdoor users should be considered while developing shaded spots in outdoor areas where people from different climates may have different perceptions of the preferred level of sunlight. Thorsson et al. (2007a) observed the attitude towards the sun and the activities associated to that such as sunbathing differed between people from diverse cultural and climatic backgrounds.

Another descriptor of the spatial features is aspect ratio, which is a proportion of the height of buildings to the width of the street. However, in this study the square form of Site 3 made it impossible to calculate and compare the aspect ratios between the sites. Furthermore, adjusting aspect ratio to enhance thermal comfort is not as straightforward as other strategies because it involves several issues that have implications for urban form. For this reason, there are advocates and opponents of this option. For instance, some local plans in Melbourne support the establishment of compact formats through urban precincts (Victorian Government 2008, The State Government of Victoria 2014); even the RMIT University has committed to transform its outdoor built environments to build a sustainable precinct through "Sustainable Urban Precinct Program" (SUPP). A part of this program is allocated to shape the buildings (including forming on average higher buildings) in which the attainment of better thermal comfort is assured.

The opponents of unusually compact designed urban forms believe that this form of design disregards neighbours' right to have public places that are liveable, attractive, welcoming which encourages the social and economic life of the city as they are inherently interconnected. The process of change in the urban form to have higher aspect ratio will face challenges such as complying with urban policies such as height control, meeting the requirements of standard on space per capita, constraints with heritage-listed buildings, etc. Challenging the current density in Melbourne's CBD, Hodyl (2015) found that "*high-rise apartment towers are being built in central Melbourne at four times the maximum densities allowed in Hong Kong, New York and Tokyo – some of the highest density cities in the world.* She then maintained that "*…this is possible because the policies used to regulate decision-making for high-rise residential developments in central Melbourne are weak, ineffective or non-existent. This enables the approval of tower developments that are very tall and that squeeze out the space between the buildings, with little regard of the impact on the streets below, or on the value of neighbouring properties*" (p. 1).

Despite the existence of some guidelines indicating the valid microclimate consequences of transformation in the urban form, the task of implementing climate-sensitive design for new urban forms is very challenging (Johansson 2006b, Klemm et al. 2013). The bio-climate implications are investigated before the design and development phases in several cases. For instance, d'Argent (2012) investigated the bioclimatic consequences of the compact city regarding thermal comfort in Melbourne. The findings were adopted in *Melbourne 5@ million* to assist with developing policies ensuring integration of urban climate in planning. However, in some circumstances the change in urban form did not necessarily contribute to improving thermal comfort conditions (Emmanuel 2005, Zacharias et al. 2004). In San Francisco, Zacharias et al. (2004) observed that providing design options in seven plazas did not statistically improve thermal conditions and having more people in outdoor spaces.

The ground surfaces and particularly pavements are known to be a determinant of outdoor thermal conditions and comfort (Pomerantz et al. 2000, Asaeda and Ca 2000, Doulos et al. 2004, Yilmaz et al. 2007, Brischke et al. 2012, Erell et al. 2014). Although the experimental design did not allow for investigating the impact of surface temperature on people's thermal comfort, the comparative results elicited valuable information on thermal performance of paving materials in RUCC. Overall, the results showed that structure of the materials used as pavement, season and light conditions were the key factors governing T_s in urban outdoor spaces (Section 6.4).

At sites 1 and 3, timber deck on average achieved the first rank as the coolest material under various light conditions (Figures 6.5 and 6.7). This finding agrees well with a study wherein the timber of 33 wood species was found to have fundamental advantages compared to several alternatives for outdoor flooring (Brischke et al. 2012). Timber possesses a low heat capacity due to its porous nature; therefore, it is not a good heat sink and nor an ideal option for outdoor applications. The timber's lower T_s is also associated with the structure of the deck; being raised up from the ground which creates a gap allowing a better air circulation and decrease in surface temperature. Brischke et al. (2012) indicated that timber's ability to improve human thermal comfort if the direct contact with human skin is inevitable; for this reason, they recommended timber decking for outdoors. Furthermore, the results from autumn measurements showed that timbers tended not to lose their surface temperature sharply and this resulted in maintaining higher T_s and lower T_a in cool seasons. Hence, the usage of this flooring option advantages human thermal comfort in outdoor spaces.

The garden beds as a green space have been long a part of outdoor settings. The usage of these spaces has been conducted with various arrangements (i.e. plants in different sizes and leaf textures, various growing medium, and bedding materials, etc.). In this study, the results showed that garden beds with bare soils or in conjunction with wood-based mulch produced considerably high surface temperature (in sites 1 and 3) unless the surface was directly overshadowed by bushes and trees (as in site 2). Such a finding could not confirm the results of some previous studies wherein the green spaces are generally reported to be a mitigation strategy to reduce surface temperature (Tzoulas et al. 2007, Alexandri and Jones 2008). However, the literature stated that the cooling effectiveness of green spaces depends on many factors, including the location and size of vegetation, the coverage of canopy coverage, planting density and irrigation practice (Shashua-Bar et al. 2011, Coutts et al. 2012). Shashua-Bar and Hoffman (2000) highlighted the fact that 80% of cooling effect in trees is achieved through shading. On this basis, since the results mean the medium is in direct exposure to sunlight it may even indicate higher temperature values than other ground surfaces. Comparing various vegetated and non-vegetated surfaces, Niachou et al. (2001) argued that vegetated spaces' T_s differs depending on the type of vegetation; they noted that while lower T_s were observed in spaces covered with thick vegetation, the higher T_s was found in the cases of spaces with spare vegetation or bare soils. Also, the results showed that green spaces could decrease the fluactuations in T_s as they act as a heat sink; the finding concurs with results of studies conducted in tropical climate (Wong et al. 2003) and Mediterranean climate (Niachou et al. 2001).

The application of AstroTurf in outdoor spaces overweighs the natural lawns due to the advantages such as being the low maintenance and cost-effective. This flooring material also provides the opportunity to sit or lie down and enjoy outdoor environments. The findings suggested that in general AstroTurf holds notably high T_s, confirming prior studies' results in various climate conditions (Devitt et al. 2007, Milone & Macbroom 2008, Yaghoobian et al. 2010, Brooks 2012, Santamouris 2013). In 2012, in a committee memorandum there was a debate on the adverse effects of AstroTurf including its high Ts (Brooks 2012). The committee suggested that its usage should be limited to certain spaces such as sport fields and its installers should moderate its application by planting shade trees in the surrounding environment. Comparing Ts above different urban surfaces, Santamouris (2013) reported 73 ˚C of Ts above artificial turf compared to 38 ˚C above the grass, and 61 ˚C above asphalt.

The results demonstrated that equally important to the material used outdoors was the level of exposure to sunlight (Section 6.5.1). The shadow pattern per se is dependent on spatial geometry, time of the year and surrounding obstacles. The varying magnitudes of T_s measured for the same materials across different sites and seasons reflect the shadow impact on thermal performance. Therefore, during the design phase for an outdoor space it is vital to note the best materials suitable for specific parts of that outdoor space. This consideration of the thermal budget will lead to better open spaces.

8.11 USAGE PATTERN IN OUTDOOR SPACES

The dynamics and determinants of the daily usage pattern in RUCC were analysed using the results obtained from field surveys (Section 6.15) and unobtrusive observations (Section 6.16) over the three seasons. A few measures were used to investigate the above-mentioned characteristics, including: purpose and frequency of visit, length of stay, spatial attraction, effect of seasonal change, type of users and activity in field surveys and the relationship between attendance and thermal conditions on one hand, and the time of day on the other hand in unobtrusive observations. In general, the results showed that these open spaces were primarily used for recreation purposes as more than half of participants indicated that "resting in the space" was their priority to visit (Figure 6.26), however, the composition of purpose of visit varied between the sites. For instance, "passage to another place" was the first choice in Site 2, which perfectly matched with the lengths of stay in this site wherein around 75% of participants visited the site for less than 10 minutes (Figure 6.27). However, the findings of field surveys contradicted that of observations; a higher percentage was reported to belong to transient users. One possible explanation is that the data collection protocol in observations counted the same people in the study site who were already considered as non-transient users in the prior observation interval. In contrast, for transient users only one minute was allocated to count people within each 30-minute interval. At each interval even people attending for a short period were deemed non-transient users.

The RUCC open sites were repeatedly attended by the surveyed people (Figure 6.28), and among the study sites, site 2 was more repeatedly frequented where more than 80% of participants indicated frequency as a "few times a week to daily visits" (Table 6.27). The reason for such a high percentage of people with the most frequencies is attributed to the location of the site where a high volume of university students and staff converged to reach their school. This explanation is backed by the findings on the type of users indicating that a considerable percentage of participants were transient users in Site 2 relative to that in other sites (Figure 6.29). From the length of stay perspective, by-season analysis demonstrated that although there were variations in the number of people attending the spaces in different seasons, the seasonal change did not significantly influence this measure and short visits on average accounted for 68% of total use. The tendency for short visit was also observed before in public spaces of Tokyo (Thorsson et al. 2007a) and a public garden in Taichung City (Huang et al. 2015).

The findings also showed a meaningful association between thermal conditions and number of people (Figure 6.36). The results corroborated the findings of previous studies under various climates (Thorsson et al. 2004a, Zacharias et al. 2004, Lin 2009, Lin et al. 2013a, Lin et al. 2012, Martinelli et al. 2015). For instance, Gaitani et al. (2007) argued that thermal perceptions determine attendance and human activities in outdoor spaces and the level of activities hinges on the extent of satisfaction or otherwise under the given thermal conditions. However, site analysis revealed much about the relationship between thermal conditions and total attendance in study sites. Clearly indicated was the role of "place character" and "thermal expectations" in people's presence outdoor. The strength of such an association varied among the study sites, which is consistent with the results of previous studies wherein the various locations had different levels of association between thermal conditions and total attendance (Thorsson et al. 2007a, Zeng and Dong 2015).

The function of the place (place character), may compromise the role of meteorological conditions by modifying thermal expectations. As a case in point, the least association was found in Site 2 wherein the main function was indicated "passage to another place" by respondents who shortly visited this site often. In this line, Thorsson et al. (2007a) also observed that thermal conditions were and were not an important factor in people's presence, respectively, in a park and urban square. The time of the day also proved to be strongly associated with the number of users attending to the study sites (Figure 6.36). The mere fact that the RUCC sites were mostly attended by the students and staff who needed to be indoors at certain hours explains the link between the time of day and number of daily visits. It means that in a specific short time there were many people arriving in the spaces to get to lectures on time. Lin (2009) stated that "…*simple* *thermal environmental factors or thermal comfort indices cannot fully explain the influence of the thermal environment on the number of people using public spaces and other non-thermal factors ought to be taken into account"* (p. 2025). In two studies on North American urban spaces the number of visitors was mainly related to some key reasons including microclimate conditions, the function of place and the time of day (Zacharias et al. 2001, Zacharias et al. 2004). Zacharias et al. (2001) found that time of day could explain the attendance of people in an urban plaza three times more than what meteorological conditions could.

8.12 SUMMARY

The discussions presented in this chapter aimed to address the research questions developed in Chapter 1. As discussed in Section 8.4, the indicators of thermal perceptions differed in indicating thermal satisfaction. Hence, as per the further analyses in this chapter, the validity of the assumptions enshrined in comfort standards corresponding thermal neutrality to thermal satisfaction was violated and it was indicated that there is a need to revise the philosophy of thermal comfort in the thermal comfort standards. Drawing on these findings and in an attempt to explain and interpret the differences with assumptions enshrined in comfort standards a multi-model framework was used. This framework employed the psychological concept of "alliesthesia" to acknowledge the effect of seasonal change on people's thermal expectations, "socio-ecological system model (SESM)" to measure the effect of contextual factors on thermal sensation and the "theory of rising expectation" to shed light on the socio-economical dimension of thermal comfort in the context of study. Discussing the analytical findings of SESM (presented in Chapter 7) environments, this chapter addressed the second research question on the extent of impact of contextual factors on people's thermal perception; moreover, it indicated the relevance and position of adaptive comfort theory in comfort research. In responding to the third research question this chapter discussed that in addition to meteorological conditions the "place character" possibly dictates the human-place relationship in outdoor spaces. On this basis, the place character is a significant factor in achievement of thermal satisfaction in public spaces.

CHAPTER 9: CONCLUSIONS

9.1 INTRODUCTION

This chapter concludes the thesis and highlights the main findings and their implications for comfort research and the management of thermal conditions in outdoor spaces. Based on the discussions in the previous chapters, this chapter briefly explains how the following research questions are addressed: Research question 1 (t*o what extent are the thermal comfort standards applicable to educational urban precincts in the context of Australian cities?"*), research question 2 (*"to what extent can contextual factors influence user's thermal perceptions?"*) and research question 3 (*"what are the factors influencing usage pattern and behaviour in outdoor spaces?"*). By addressing the research aim: the applicability of assessment method of thermal comfort in the context of Melbourne, this chapter summarises how the responses to these research questions can contribute to the theory of comfort in outdoor spaces. The remaining sections are allocated to describing the contribution made by this thesis to the body of thermal comfort knowledge, limitations, and recommendations for further studies.

9.2 SUMMARY OF STUDY

Successful urban open spaces can contribute to making people's day-to-day lives better. On this basis, outdoor spaces can also alter the local microclimate and minimise the potential thermal stress, improve outdoor activity and promote the use of more green ways of transport including walking and cycling. This will also lead to further improvements in living conditions by decreasing energy consumption, pollutants emissions, and resultant heat island effects. Furthermore, encouraging a wider public to use outdoor spaces is beneficial from several perspectives including economic, environment, social and individual physical conditions. The first step to building sustainable outdoor spaces is to understand the interaction of people and outdoor built environments particularly with respect to outdoor thermal conditions. This thesis aimed to assess the pattern of thermal perceptions and usage behaviour among people in three sites situated in an education precinct. The study was particularly interested in discovering whether the available comfort standards including ASHRAE 55 (2010) and

ISO 7726 (1998) were applicable in Melbourne with its Oceanic climate to specify comfort conditions.

To achieve the research objectives, this study adopted a three-stage methodology involving three data collection methods: questionnaire survey, field measurement, and unobtrusive observation. These methods are standard practice in comfort research. The meteorological conditions of case studies were monitored using two measuring systems: mobile and stationary weather stations. In addition to obtaining actual comfort conditions as indicated by participants, this study employed three thermal comfort indices (PET, UTCI, OUT-SET*) to predict the thermal comfort conditions. Furthermore, the usage pattern of these three open spaces was assessed using field observations coinciding with the field measurements. In total, 1059 questionnaires were collected during three rounds of data collection (spring 2014, summer 2015, autumn 2015). Four thermal scales indicated people's thermal assessments: thermal sensation, thermal preference, thermal acceptance, and overall comfort. Accordingly, a multi-model framework served to explain the research findings. These models included socio-ecological system model (SESM), alliesthesia, and rising expectations. Additionally, these theories were used to explain the divergence found between people's actual thermal perceptions and assumptions in comfort standards. The following sections present the summary of findings and their practical implications for the field of comfort research.

9.3 SUMMARY OF FINDINGS

9.3.1 COMFORT, STANDARDS, AND NEEDS FOR REVISIONS

"to what extent are the thermal comfort standards applicable to education urban precincts in the context of Australian cities?"

The findings from people's thermal responses represented different perceptual connotations. These differences were used to test the research hypothesis by showing how the assumptions enshrined in thermal comfort standards on thermal satisfaction applied to people's thermal perceptions. As presented in Chapters 6 and 8, it proved that the connotation of "thermal neutrality", that is the basis of thermal comfort standards, was not the ideal or preferred thermal conditions among the survey participants. This study suggested that "thermal expectations" is the root reason for the divergence observed concerning the characteristics of "thermal satisfaction" assessed per standards, and otherwise. As the thermal expectation is not accounted for in the comfort assessing methods entrenched in comfort standards, the study further investigated how this important factor played a role in shaping people's subjective assessments of thermal conditions in outdoor spaces.

The results of this study showed that the existing comfort standards (ASHRAE 55 2010, ISO 7730 2006) are inadequate to apply in the study context. The main goal of these standards is to specify thermal satisfaction for many people by defining neutral temperature (T_n) and comfort/optimal thermal range. The standards, which were initially developed for indoor conditions, suggest that people achieve thermal satisfaction at T_n, which is situated in an optimal thermal range that is in turn obtained using three central categories of the ASHRAE thermal sensation scale. However, the relationship between thermal satisfaction and thermal neutrality is not always straightforward. In this study, the findings elucidated that thermal preference (T_{pref}) was outside the acceptable thermal range that was computed based on the recommendations in standards. However, T_{pref} determined for all seasons and the whole period of study fell within the range, resting on direct votes on thermal acceptability. Furthermore, these results revealed that neutrality is not necessarily perfect for many people. This contradiction suggests that comfort relies on a connotation of neutrality that may not be appropriate. Hence, it can be argued that the assumptions made in standards cannot be thoroughly applied to the context of this study.

Accordingly, this study provided an opportunity to reconsider the philosophy of comfort with reference to human thermal preference and expectations. It also raises awareness of the need to develop standards that are context-specific and consider the social norms, dominant culture, people' attitude sand behaviours, and the adaptive opportunities available in the society of interest. The other issue with the application of thermal comfort standards is the assessment method of thermal comfort prediction and particularly the comfort indices. The comfort standards recommend the use of steady-state driven indices; however, as the results proved these indices are not fully applicable in outdoor conditions where most of the users were in non-steady state conditions. Hence, this research provided insights into the limitations and abilities of using widely employed comfort indices in thermal comfort research. It also highlights the need for developing assessment procedures that fully capture real-world conditions in outdoor spaces. Returning to the hypothesis posed at the beginning of this study, with the analytical findings obtained, it is now possible to confirm the cogency of the research hypothesis on the inadequacy of comfort standards to assess determinants of thermal comfort conditions in outdoor spaces.

9.3.2 CONTEXTUAL FACTORS AND THERMAL SENSATION

"to what extent can contextual factors influence user's thermal perceptions?"

In line with the adaptive approach theory, the analytical results obtained from an investigation of contextual factors clustered under the five environments of SESM showed that some of these factors modified people's thermal sensations. These factors included participants' age, skin colour, level of exposure to sun and clothing insulation in individual environment; the participants' climatic background, position, and companionship in social environment; weather conditions, SVF and time of exposure to outdoor thermal conditions in physical environment; seasonal change, overall comfort, thermal preference, place character and sub-factor of "environment with better ambient conditions" in a psychological environment.

In the light of adaptive theory, this study confirmed that people are active recipients of thermal conditions rather than being passive agents and contextual factors influenced people's thermal perceptions and expectations. The results provided a great deal of information on how to control the contextual factors for better thermal comfort achievement in outdoor spaces. Another implication of the information is to develop guidelines that account for these factors; these guidelines in turn will offer assessment techniques that specify thermal satisfaction thresholds in outdoor conditions that are valid. For instance, knowing that longer exposure to outdoor conditions will modify people's thermal expectations and thus their thermal sensations, space managers can take measures to first encourage people to attend open spaces and then to facilitate their extended period of stay outdoors.

9.3.3 APPLICATION OF CONCEPT OF ALLIESTHESIA IN ASSESSMENT OF THERMAL COMFORT

This research illustrated the footprint of thermal pleasure through the psychological concept of alliesthesia to change people's thermal expectations. Alliesthesia is particularly effective in relation to seasonal change and transient thermal experience outdoor. On this basis and as discussed in the previous chapter, the implications of this finding are concerned with the necessity to define thermal comfort conditions specific to each season and people's thermal expectations. In other words, to draw reliable interpretation of field survey data, one not only should take people's thermal expectation of the study season but also consider the prior thermal conditions. Furthermore, this study indicated that understanding the role of alliesthesia in the experience of transient thermal conditions that prevails in outdoor spaces deserves more attention. Therefore, researchers assessing outdoor thermal comfort conditions need to closely note the effect of thermal pleasure on thermal sensation, since most outdoor users tend to stay for a short amount of time; otherwise, there is a risk of misinterpreting subjective assessments by those who just stepped out from an indoor setting.

9.3.4 RISING EXPECTATIONS AMONG THE USERS OF OUTDOOR SPACES IN RUCC

As noted in Section 8.7.2, the main conclusion from applying the theory of rising expectation on the observed field survey data relates to the importance of the contextual conditions and target population. It is important to acknowledge the characteristics of the target population, knowing how they interact with outdoor thermal conditions, what their expectations of thermal conditions are and how individuals compromise their thermal preference in favour of spending time outdoors. This study suggested that beyond the effect of thermal conditions, there is a socio-economic overlay to people's thermal expectations. This overlay proved to make people in this case study have higher thermal expectations. Particularly, as people attended the study sites were from diverse climatic backgrounds with higher expectations set, it is assumed that the main driver of higher thermal expectations among the survey outdoor users was their socio-economic status. Therefore, the research findings recommend that in comfort investigations in public spaces in developed countries with multinational users and developing countries with high rate of immigration, the focus must be placed on factors pertaining to socio-economic status.

9.3.5 USAGE PATTERN IN EDUCATION PRECINCTS

"what are the factors influencing usage pattern and behaviour in outdoor spaces?"

Usage pattern in RUCC's open spaces was found to predominantly relate to "time of day" and "microclimate conditions". The strength of these relationships, however, was not consistent over the study sites. As discussed in the previous chapter, the results highlight the significance of character of place according to which people's usage may differ. Therefore, in addition to considering climate conditions in the design and development of spaces, it is important to define a character for spaces that serve their intended purposes.

The major implication of this finding is that space managers can better manage outdoor spaces when they become informed of its determinants. Better management may include providing facilities such as opportunities for thermal adaptation for outdoor users with the aim of encouraging more people to attend outdoors. As adaptation opportunities sometimes involve devising energy intensive options, the results of this study that characterised the busiest time of a day (9:00 am to 5:00 pm) and importance of meteorological conditions in relation to people's presence will assist space managers to implement best management practice. In general, attending outdoor spaces in an education precinct can enhance students' physical and psychological health and improve their academic performance.

9.4 CONTRIBUTION TO THEORY, KNOWLEDGE, AND PRACTICE OF THERMAL COMFORT

This study contributed to the theory and practice of thermal comfort from different perspectives. The analysis of thermal responses provides a new understanding about the meaning of thermal comfort among the visitors of outdoor spaces in an education precinct located in a densely-urbanised area. This understanding contributes to re-evaluating the traditional theory of thermal comfort. It also questions the validity of its fundamental notion of thermal acceptability and hence highlights the definite need for revising and extending the current thermal comfort standards to offer applicable comfort assessing techniques in outdoor spaces. For this purpose, the field survey data obtained in this study is a valuable source of information through which researchers may develop guidelines specifying thresholds of thermal satisfaction in public spaces in Australian cities.

The other contribution to the theory of thermal comfort is the introduction of the multi-model theoretical framework enables the evaluation and assessment of thermal comfort conditions in highly urbanised spaces in a developed society. This framework provides the opportunity to investigate the impact of contextual factors on people's thermal perceptions; it also set the groundwork to interpret the pattern of people's thermal responses collected in an education precinct situated in a financially advantaged society. Particularly, the SESM framework can model outdoor thermal comfort in studies in line with adaptive comfort where the characteristics, attitudes and behaviours of thermal recipients are central.

Similar to few other studies, this research acknowledges the pivotal role of "thermal expectations" in shaping people's thermal satisfaction in outdoor spaces. This connotation is often overlooked in the assessment of thermal comfort, which commonly leads to misinterpreting the research findings. In this regard, the research demonstrates how thermal expectations may alter people's thermal judgement and emphasises the concept of alliesthesia to explain thermal responses obtained in different seasons. Lastly, the research contributes to the knowledge of thermal comfort in outdoor spaces by linking relatively different thermal satisfactions in the various urban spaces to the concept of place character. As evidenced in this study, place character among others is most likely one cause of change in thermal expectations. The research findings, hence, can be used to reinforce or advance the theories explaining the impact of place characteristics on people's attitudes and behaviours. This research contributes to informing the best practice management of educational outdoor spaces. The results will help managers of these spaces to know the usage pattern and how people interact with outdoor built environments under various thermal conditions. This way they can better plan successful outdoor spaces that are used to their best advantage. Finally, the results obtained in this study can be applied to similar climate and cultural contexts where the focus is to understand thermal comfort requirements in public outdoor spaces including educational precincts.

9.5 LIMITATIONS

A few caveats need to be noted in the present study. There were certain limitations that emerged during the data collection stages. The first limitation is the fact that field surveys (incl. questionnaire surveys and mobile measurements) were not simultaneously carried out between the case studies. Technically, the results emerging from concurrent field surveys could provide useful information about how people are interacting with outdoor built environments in different spaces the exact similar thermal conditions. It also could better depict the role of place character in shaping people's thermal perceptions. This limitation was primarily related to the logistics and human resources as the nature of this PhD research does not allow the researcher to benefit from assistance. However, to overcome this limitation a set of thermal ranges was defined in which thermal responses obtained from different sites were analysed and compared.

The other limitation relates to the inadequacy of steady-state driven comfort indices in the prediction of thermal perceptions in transient thermal conditions of outdoor spaces. As discussed in Chapter 2 there are several reasons explaining why the predictions produced by these indices are not quite valid within the highly variable thermal conditions of outdoor settings. However, as the results showed when the effect of individual differences was reduced by considering average of indices temperature and thermal responses, the relevance between predictions and observed comfort data improved. Although the main aim of the research was to evaluate the applicability of current indoor thermal comfort standards, the absence of a robust procedure for assessing techniques to examine the level of thermal comfort in outdoor spaces is always a technical limitation.

In open spaces, the microclimates conditions can be varied from locations to locations, thus by using just few points of measurement, the link between the physical environment and thermal perceptions is simplified. There are few other factors which are not captured or considered in this study. However, not all of these factors are quantifiable, nor it was possible to procure the required expensive equipment and hire assistants to fully investigate them within a PhD research project. Several researchers will have to resort to using various simulation to understand such impact and relationship.

The limitation in research methodology regarding the lack of formal interviews hindered acquiring in-depth qualitative responses about the survey population's opinions, thermal judgments and expectations of outdoor thermal conditions. This would have given a more realistic insight into the dynamics of thermal comfort in open spaces of an urban precinct. Despite this limitation in the data collection process, the researcher organised the questionnaire so that the maximum information was elicited from participants. In addition, where possible, the researcher noted down participants' statements about thermal conditions and the study spaces they visited.

There was also a limitation in the use of appropriate equipment specific to outdoor spaces due to their unavailability at the time of study. For instance, the use of black-painted globe thermometer (150- mm) which was used instead of a grey-painted 38-mm diameter globe thermometer as suggested by outdoor thermal comfort studies. Lastly, although this globe thermometer required 20 minutes of wait time as specified in comfort standards, in this study there were limited occasions where only 10 minutes was allowed for the thermometer to reach equilibrium. This limitation was mainly due to people's usage pattern including short visits (5-10 minutes) resulting in moving the weather station frequently within shorter intervals. The pilot study results also showed that 10 minutes was enough for the used weather station to reach equilibrium.

However, the pilot study showed that 10 minutes was enough as a response time, also in most cases during the surveys moving the mini weather station was limited.

9.6 FURTHER STUDIES

The findings of this study broadened the understanding of thermal comfort requirements in outdoor spaces of an education precinct in Australia and taken together, this research will serve as a basis for future studies. As this study suggested, thermal satisfaction depends on people's thermal expectations. On this basis, further studies are highly recommended to scrutinise the dimensions of thermal comfort relating to human psychology and cognition, which will further provide a clearer picture of the role of thermal expectations in the matrix of thermal perception.

This study showed that urban form is also critical in the determination of thermal conditions and comfort outdoors. Hence, it is suggested that further studies identify the differences in thermal satisfaction between public spaces with distinct urban forms. In this regard, usage of simulation tools to understand the effect of different urban forms and features can be quite helpful. Integrating simulated effects of various urban features into the results of the field survey data enables urban designers to understand and further compare and optimise the different design options without physical modification of open spaces which can be money and time intensive. The simulation can also assist in defining the meteorological conditions of sub areas within an open space, which have different functions; consequently, their users may require different levels of thermal comfort. For instance, the meteorological conditions in pathways and sitting areas can be modified to serve their different purposes.

As a comparative evaluation, studies yield invaluable information about the function and interactions between a set of parameters in each system or society. Further studies are needed to explore whether the main findings of this research on human-place relationship such as thermal expectations or impact of contextual factors will resemble other target population(s). The result will verify the generalisability of the specified thermal comfort requirements within the contexts of people with differing characteristics and test the validity of interpretations presented in this study for the patterns of people's thermal judgement.

Finally, it is suggested that further research can investigate the mechanisms where people's thermal expectations can be modified for more attendance in outdoor settings. This investigation may include finding the major motivations including people's needs and preferences, which encourage them to attend an outdoor space. It is also advantageous to review the available policies or contribute to developing new policies and incentives that influence people's usage patterns.

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APPENDICES

APPENDIX A: Invitation to participate form

RMIT UNIVERSITY

School of Property,
Construction and
Project Management

GPO Box 2476
Melbourne VIC 3001
Australia

Tel. +61 3 9925 2230
Fax +61 3 9925 1939

INVITATION TO PARTICIPATE IN A RESEARCH PROJECT

Project Title:

EVALUATION OF MICROCLIMATES AND THERMAL PERCEPTIONS OF URBAN PRECINCTS

Investigators:

- *Salman Shooshtarian, PhD Candidate, salman.shooshtarian@rmit.edu.au, +61(3)9925 1724*

Date: xxxxx

Dear Participant,

You are invited to participate in a research project being conducted by RMIT University. Please read this sheet carefully and be confident that you understand its contents before deciding whether to participate. If you have any questions about the project, please ask one of the investigators.

Who is involved in this research project? Why is it being conducted?

My name is Salman Shooshtarian, a PhD candidate at the School of Property, Construction and Project Management (PCPM). This research is conducted as part of my PhD research and aims to further the knowledge on the impacts on human thermal comfort in urban precincts. The research plan for this project has been approved by RMIT University's Human Research Ethics Committee.

I will undertake the data collection and analysis of the research project under the supervision of the primary supervisor, Assoc Prof Usha Iyer-Raniga and associate supervisor, Dr Mary Myla Andamon from the School of Property, Construction and Project Management.

Why have you been approached?

To evaluate the thermal conditions of different urban morphology it is necessary to conduct measurements of the physical environment and to collect information of the perceptions of conditions by RMIT University outdoor users. As a user of outdoors in RMIT University City Campus you are invited to participate in this survey. You will be asked to complete the OUTDOOR THERMAL ASSESSMENT AND PERCEPTION survey. This survey addresses the overall impressions and satisfaction with a range of features of the selected study sites. It also includes a series of questions addressing the immediate comfort, clothing and activity levels.

What is the project about? What are the questions being addressed?

The main aim of this research is to assess the thermal conditions and associated thermal comfort in various study sites which represent outdoor settings across Melbourne, Victoria. This research is also intended to identify the factors influencing human thermal comfort throughout a year. Your responses through the survey questionnaires will provide quantitative and qualitative information identifying environmental issues on the real impact of urban elements including green spaces on human thermal comfort.

If I agree to participate, what will I be required to do?

This study seeks to understand your judgment relating to thermal conditions of your immediate environment. The survey should take **10 to 15** minutes to complete. While this survey is being completed, physical measurements of the climatic conditions of immediate surrounding will be recorded. The whole procedure will be as unobtrusive as possible.

Participant Information Sheet *Page 1 of 2*

RMIT UNIVERSITY

What are the possible risks or disadvantages?

There are no perceived risks regarding the participation in this research beyond your normal routine activities. However, if you are unduly concerned about your responses to any of the questionnaire items or if you find participation in the research project distressing, please do not hesitate to contact Assoc Prof Usha Iyer-Raniga or Dr Mary Myla Andamon, details provided below. You will be able to discuss your concerns confidentially, including options to withdraw from the research and suggest appropriate follow-up, if necessary.

What are the benefits associated with participation?

This research study will form part of a larger study aimed at information on the provision of comfortable environments in urban precincts. The outcomes of this research can provide knowledge to better understand the role of green space elements in the moderation of human thermal comfort. As a transient resident in this campus, you will benefit from having an outdoor environment where its thermal conditions are improved using vegetation.

What will happen to the information I provide?

The answers to the survey will be treated in the strictest confidence, no individual results will be available to anyone and no one will be referred to by name in the report. The results from the survey responses will be organised and reported in the form of aggregated data only. Aggregated outcomes will be published in research papers and industry magazines or similar publications. The PhD thesis will be published on Appropriate Durable Record (ADR) in the RMIT Online Repository and this is a publically accessible online library of research papers. The research data will be kept securely at RMIT University for a period of 5 years after publication, before being destroyed. Due to the nature of data collection, we are not obtaining written informed consent from you. Instead, we assume that you have given consent by your completion and return of the questionnaires.

What are my rights as a participant?

The success of this research project hinges on the role of volunteers. You are not under any obligation to complete the questionnaire and you may quit at any stage, should you wish to do so. You may ask any questions any time during the survey. As there is a possibility of disclosing photographs of questionnaire administration you have the right to be de-identified in any of photographs intended for use in any publication. Your consent will be sought prior to publication of any photographs taken during the survey.

Whom should I contact if I have any questions?

Should you have clarifications and require further information regarding this research project, please get in contact via:

Yours sincerely

Salman Shooshtarian, PhD candidate
Email: salman.shooshtarian@rmit.edu.au
Telephone: +61 3 9925 1724

If you have any concerns about your participation in this project, which you do not wish to discuss with the researchers, then you can contact the Ethics Officer, Research Integrity, Governance and Systems, RMIT University, GPO Box 2476V, Melbourne, VIC 3001. Tel: (03) 9925 2251 or email: human.ethics@rmit.edu.au

Participant Information Sheet *Page 2 of 2*

APPENDIX B: Questionnaire and Supplementary observation sheet

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OUTDOOR THERMAL ASSESSMENT AND PERCEPTION SURVEY

Note: As this questionnaire is voluntary, you are not under any obligation to complete it.
The researcher is grateful for your time by participating in this survey
This survey will take approximately 10 to 15 minutes to complete

Date: ________ **Code:**______ **Time:** ___: ___am/pm

1. **Personal details** please specify your personal details according to the following items.

   1a. Age: ☐1 under 18 ☐2 18-30 ☐3 30-45 ☐4 45-60 ☐5 above 60

   1b. Gender: ☐1 M ☐2 F

2. **What brings you here? *Check all that is applicable.***

   ☐1 having a break ☐2 getting fresh air ☐3 resting ☐4 passage to another place
   ☐5 change of environment ☐6 having lunch/snack ☐7 read/write ☐8 meeting/waiting for someone
   ☐9 others (please specify)_____________.

3. **How long have you lived in Melbourne (Australia)?**

   2a. Since birth: ☐ Yes ☐ No

   2b. If not since birth,

   ___ year(s) ____ month(s) Where is your place of birth-------------- /last residency? _________.

4. **How often do you come to/pass this place?**

   ☐1 daily ☐2 several times/week ☐3 a few times/week ☐4 a few times/month ☐5 rarely ☐6 first time

5. **How have you spent your last 30-60 minutes prior to this survey?**

   ☐1 walking ☐2 standing ☐3 sitting ☐4 sleeping ☐5 others (please specify)_______.

6. **Where were you 15 minutes prior to this survey?**

   ☐ indoor non-ventilated space ☐ indoor- conditioned space ☐ outdoor-under shade ☐ outdoor- exposed to sunlight

7. **How do you perceive the temperature at the moment? Please tick on the scale below.**

cold	*cool*	*slightly cool*	*neutral*	*slightly warm*	*warm*	*hot*
-3	-2	-1	0	+1	+2	+3

8. **I find this environment:**

   ☐1 very comfortable ☐2 moderately comfortable ☐3 slightly comfortable ☐4 just right ☐5 slightly uncomfortable ☐6 moderately uncomfortable ☐7 very uncomfortable

"Please note that questions are printed on both sides of this page."

School of Property, Construction and Project Management
RMIT University
Melbourne, Australia

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9. Please indicate your preference:

I want the temperature to be	☐ cooler	☐ no change	☐ warmer
I want the wind speed to be	☐ lower	☐ no change	☐ higher
I want the solar radiation to be	☐ weaker	☐ no change	☐ stronger
I want the humidity to be	☐ lower	☐ no change	☐ higher

10. What measures would you take to feel more comfortable? *Check all that are applicable.*

☐ use umbrella/hat ☐ move to shade (shelter/tree) ☐ reduce clothing ☐ others (please specify)

11. Which of the following statements about this particular place is close to your opinion?

☐ I agree that more natural green spaces should be established in this place
☐ I have no idea about establishment of natural green spaces in this place
☐ I disagree that more natural green spaces should be established in this place

12. Which feature(s) do you find attractive in this place? *Check all that is applicable.*

☐ plants and exposure to nature
☐ an environment with better ambient conditions
☐ beauty of the place compared to other environments
☐ convenient access and closeness to my school
☐ others (please specify)__________.

Participant's Consent

I agree that photographs will be taken while I am completing this survey and these might be used in future publications. I am assured that I will not be identifiable.

Participant: ______________________________ Date: __________
(Signature)

Thank you.

School of Property, Construction and Project Management
RMIT University
Melbourne, Australia

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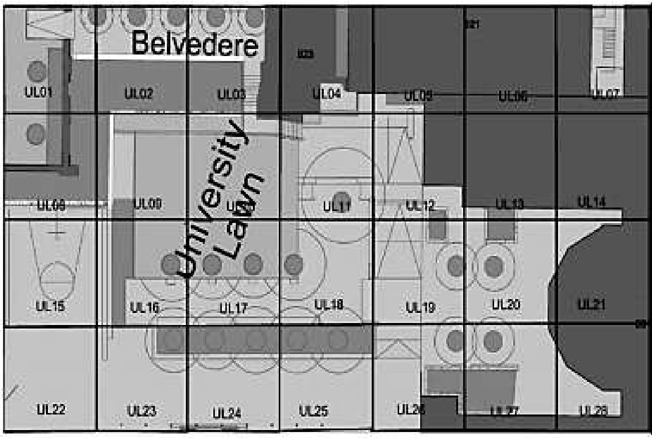
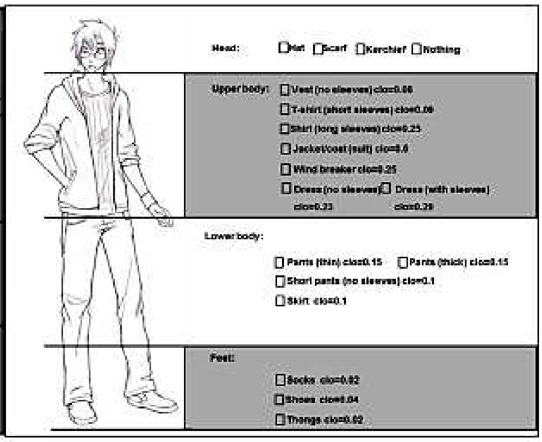
	SITE 1	
Time:		**Personal Code:**
Date:		**Area Code:**





The skin colour: ☐ dark ☐ light

Participant exposure: ☐ sun ☐ shade

Participant posture ☐ standing ☐ sitting ☐ lying down

Companionship: ☐ alone ☐ 2 ☐ >2

Other belongings: ☐ sunglass ☐ hat ☐ umbrella ☐ nothing

Academic position ☐ student ☐ professional staff ☐ academic ☐ visitor

Gender ☐ M ☐ F

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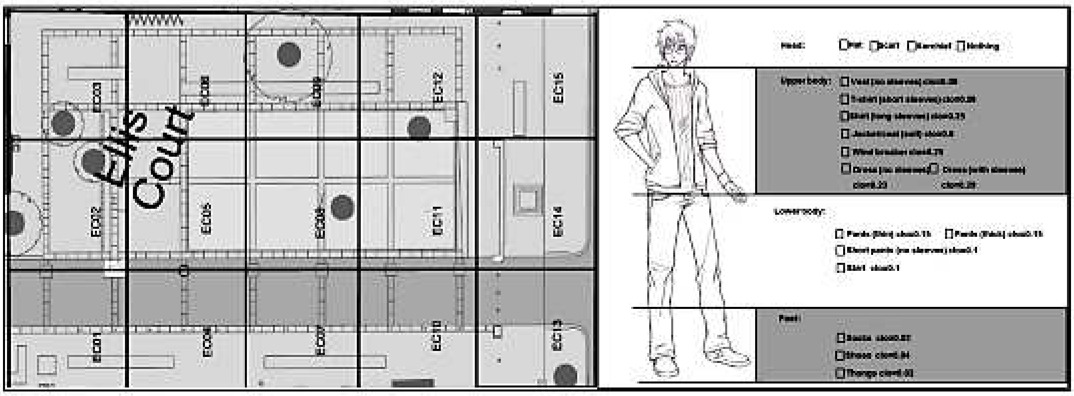
SITE 2

Time: **Personal Code:**

Date: **Area Code:**



The skin colour:	☐ dark	☐ light		
Participant exposure:	☐ sun	☐ shade		
Participant posture	☐ standing	☐ sitting	☐ lying down	
Companionship:	☐ alone	☐ 2	☐ >2	
Other belongings:	☐ sunglass	☐ hat	☐ umbrella	☐ nothing
Academic position	☐ student	☐ professional staff	☐ academic	☐ visitor
Gender	☐ M	☐ F		

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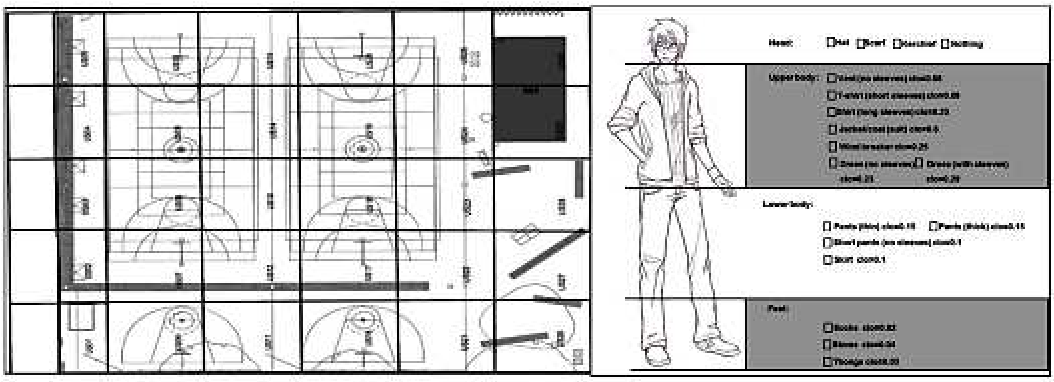
SITE 3

Time: **Personal Code:**

Date: **Area Code:**



The skin colour: ☐ dark ☐ light

Participant exposure: ☐ sun ☐ shade

Participant posture ☐ standing ☐ sitting ☐ lying down

Companionship: ☐ alone ☐ 2 ☐ >2

Other belongings: ☐ sunglass ☐ hat ☐ umbrella ☐ nothing

Academic position ☐ student ☐ professional staff ☐ academic ☐ visitor

Gender ☐ M ☐ F

APPENDIX C: Observation log form

Observation Log Date:----/----/---- *Site:*

Time	Sitting			Standing			Lying down			Moving		Loneliness	Total No	Sun/Shade	Note
Activity	Eat	Study	Talk/rest	Talk/phone	Smoke	Eat	Eat	Study	Sunbath/ rest	Play	Pass by				
9:00															
9:30															
10:00															
10:30															
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